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National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 1
INTRODUCTION AND SUMMARY

Prepared By The:
SPACE STATION TASK FORCE

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FINAL EDITION

NASA

National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 1

INTRODUCTION AND SUMMARY

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PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
BOOK 6	SYSTEM OPERATIONS
BOOK 7	PROGRAM PLAN

SPACE STATION PROGRAM DESCRIPTION DOCUMENT
BOOK 1 - INTRODUCTION AND SUMMARY

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1.0 INTRODUCTION

In his State of the Union address in January, 1984, President Reagan directed NASA "to develop a permanently manned Space Station and to do so within a decade." This directive culminated two years of NASA's effort to demonstrate the concept of a Space Station as the next logical step in space (following the development and success of the Space Shuttle). Part of this effort included preparation of a Program Description Document, which is summarized here in final form.

1.1 SPACE STATION PROGRAM DESCRIPTION DOCUMENT

The Program Description Document is a product of the Space Station Task Force. It consists of six volumes, called "Yellow Books," that define the Task Force recommendations in the areas of mission requirements, system requirements, and program planning. Early draft versions were prepared during the concept development phase providing focus to the Agency's Space Station preliminary planning activities. The final edition consolidates the results from extensive studies and analyses and is a primary input to the request for proposal (RFP) for the Space Station definition phase. This final edition coincides with the evolution of the Task Force into a Program Office and will serve as a reference document for the continuing program effort.

The individual volumes of the Space Station Program Description Document are listed below and are summarized in Sections 2.0 through 7.0 of this document.

Book 1 - Introduction & Summary. Book 1 provides a summary of the Program Description Document.

Book 2 - Mission Description. Book 2 identifies realistic science and applications, commercial, and technology development missions appropriate to the Space Station Program. It also establishes time-phased mission requirements synthesized from the various industry studies and the results from in-house studies.

Book 3 - System Requirements and Characteristics. Book 3 develops the Space Station configuration concepts, architecture, and system requirements as driven by the missions to be implemented. The requirements address both missions that will be carried out on-board the Station and missions that will be supported from the Space Station.

Book 4 - Advanced Development. Book 4 outlines the technology and advanced development programs required to support the Space Station. The technology program identifies key technology options that have the potential for enhancing the desired operational Space Station. The advanced development program provides the means of advancing selected technologies and demonstrating feasibility and performance before implementing into the Space Station design. The program is designed to support the initial Space Station and the evolutionary growth capability.

Book 5 - System Definition. Book 5 was not issued as an individual Book. The system architecture and design concepts are summarized in Book 1 and reflected in other books of the Program Description Document.

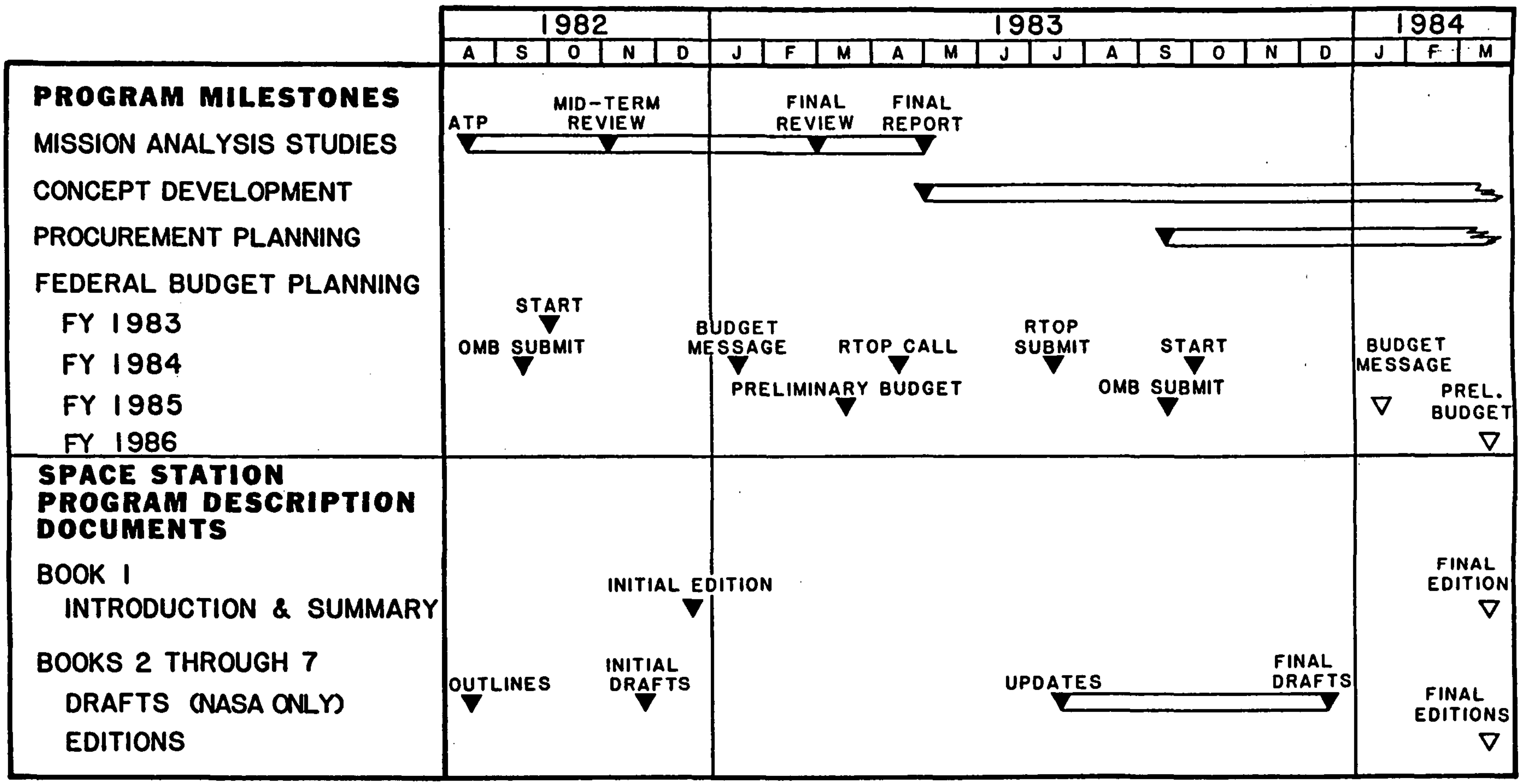
Book 6 - System Operations. Book 6 addresses the operational philosophies developed and the operational requirements necessary to satisfy the missions outlined in Book 2.

Book 7 - Program Plan. Book 7 defines the program planning and objectives and describes the overall management, technical, and procurement approaches.

Figure 1-1 illustrates the Program Description Document publication schedule.

FIGURE 1-1

SPACE STATION PROGRAM DESCRIPTION DOCUMENTS PUBLICATION SCHEDULE



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1.2 SPACE STATION TASK FORCE

A Space Station Program will influence the way NASA conducts future space operations by involving a large segment of the Agency in a more integrated way than has been experienced in the past. This is due to the activities associated with developing technology for the Space Station and the wide base of potential users in the areas of science and applications and commercial endeavors. This anticipated operating environment is reflected by all NASA organization elements being active participants in defining and preparing for the Space Station.

This broad Agency participation was focused and coordinated by the Space Station Task Force, an ad hoc organization formed by NASA Administrator James Beggs on May 20, 1982. The Task Force was staffed with individuals detailed and on loan from several Headquarters program offices and each of the NASA Field Centers. John D. Hodge was the Director of the Task Force; Robert F. Freitag was the Deputy Director. They reported to Philip E. Culbertson, Associate Deputy Administrator. The Task Force charter was to provide focus and direction for all Agency Space Station activities and to identify mission requirements for the overall program. In addition, the charter was to establish a sound technical foundation for Space Station definition in support of the Administration's review of the NASA proposal to proceed with a manned Space Station. Finally, the charter called for a program plan for system definition and development.

The initial job of the Task Force was to identify mission requirements for a space station program. This was accomplished through a series of activities involving the science community, the Department of Defense (DOD), potential international partners, and U.S. aerospace contractors. Eight mission analysis study contracts were awarded to major U.S. aerospace firms for the purpose of identifying and developing user requirements for the Space Station in the mission areas of space science and applications, commercial use of space, and national security.

Several foreign governments including Canada, Japan, and the European Space Agency conducted, at their own expense, parallel studies similar to the mission analysis studies. The results of the U.S. and foreign studies were informally exchanged at key points during the planning process.

Parallel to the contracted activities, the Agency initiated a series of technical studies within the NASA Field Centers. These in-house analyses and studies were focused through Space Station Task Force Working Groups formed in the summer of 1982. The Mission Requirements Working Group was responsible for interfacing with the user community and synthesizing the identified user missions into a set of time-phased mission requirements. An Operations Working Group was responsible for defining operational philosophies and operational requirements. A Systems Requirements Working Group was responsible for identifying requirements and characteristics of a Space Station program. A Systems Definition Working Group was responsible for defining and conducting system, sub-system, and operational trade studies and for assessing Space Station architectural functions and potential configuration options. A Program Planning Working Group was responsible for defining alternate acquisition and management strategies for the definition and development phases of the program. A Concept Development Group was formed in the spring of 1983 and led the Agency-wide systems engineering and integration effort to develop Space Station concepts, architecture, and system requirements.

In addition to the activities initiated by the Space Station Task Force, other NASA offices initiated complementary activities in the areas of technology development, science and applications, mission requirements studies, free-flying satellite and platform analyses, ancillary system studies (e.g., Orbital Transfer Vehicle and Orbital Maneuvering Vehicle), and Space Station tracking and communications studies.

The Office of Aeronautics and Space Technology (OAST) established a Space Station Technology Steering Committee (SSTSC) in November of 1981 to advise on the formulation of a technology program to support the initial Space Station and its evolution. The membership included representatives from each NASA Field Center and participating Headquarters program offices. The SSTSC was assisted by ten discipline-oriented working groups composed of the Agency's technology experts in the definition of an advanced development program to support the Space Station.

The Office of Space Sciences and Applications (OSSA) sponsored a series of summer studies by the Space Science Board and the Space Applications Board (National Academy of Sciences) to identify the requirements for science and applications missions that might be performed on a Space Station or on free-flying satellites and platforms supported from a Space Station.

The Office of Space Flight (OSF) is defining the ancillary systems necessary for operations from the Space Station and for space platforms that will fly in conjunction with it. The ancillary systems include the Orbital Maneuvering Vehicle (OMV) which provides the transportation link between the Space Station and companion free flyers, the Orbital Transfer Vehicle (OTV) which provides the transportation link between the Space Station and geostationary orbit and beyond, and other equipment required for both manned and automated servicing of payloads and free flyers.

The Office of Space Tracking and Data Systems (OSTDS) sponsored an in-depth study of communications, data systems services, functions, and descriptions of the initial physical elements by which such services and functions could be provided. This study included consideration of the total system beginning with the data source (instrument) in space and ending with the user of that data on-board the Space Station or on the ground.

These activities were for the most part performed by NASA staff within each of the Field Centers. Each Center established a focal point for coordinating the tasks at that Center and the overall effort was coordinated by the Space Station Task Force.

Table 1-1 summarizes the key milestones discussed above.

TABLE 1-1

MAJOR MILESTONES AND ACTIVITIES UNDER THE SPACE STATION TASK FORCE 5/82 - 5/84 (PARTIAL LIST)

DATE	MILESTONES AND ACTIVITIES
5/82	CREATION OF THE SPACE STATION TASK FORCE
6/82	RFP RELEASED FOR THE MISSION ANALYSIS STUDIES (MAS)
7/82	NATIONAL SPACE POLICY GOALS ESTABLISHED
8/82	MAS STUDIES BEGAN
4/83	CONCEPT DEVELOPMENT GROUP ESTABLISHED
4/83	FINAL MAS REPORTS
5/83	MISSION SYNTHESIS WORKSHOP AT LANGLEY
7/83	NASA ADMINISTRATOR ESTABLISHED THE GOALS OF THE SPACE STATION PROGRAM

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TABLE 1-1
MAJOR MILESTONES AND ACTIVITIES UNDER THE SPACE STATION TASK FORCE
5/82 - 5/84
(PARTIAL LIST)
(CONTINUED)

DATE	MILESTONES AND ACTIVITIES
8/83	FINAL BRIEFING TO THE SENIOR INTERAGENCY GROUP (SIG)
8-9/83	SPACE STATION MANAGEMENT COLLOQUIUM
10/83	AIAA/NASA SPACE STATION POLICY, PLANNING AND UTILIZATION SYMPOSIUM
1/84	PRESIDENT REAGAN CALLS FOR THE DEVELOPMENT OF THE SPACE STATION IN THE STATE OF THE UNION ADDRESS
2/84	LEAD CENTER MANAGEMENT APPROACH DESIGNATES JSC AS LEVEL B, OTHER CENTER ASSIGNMENTS MADE
3/84	ADMINISTRATOR'S INTERNATIONAL VISIT
4/84	INTERIM SPACE STATION PROGRAM OFFICE ESTABLISHED

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1.3 SPACE STATION HISTORICAL PERSPECTIVE

Since the Program Description Document represents the state of Space Station planning through early 1984, a concise historical summary is included in order to place the program and this document in an overall perspective. A more comprehensive summary, written by Dr. Sylvia Fries, is available from the NASA History Office.

Serious engineering design of space stations pre-dates the creation of the National Aeronautics and Space Administration in 1958. Setting aside the fanciful visions of writers in the 1800's, U.S. space station designers of the 1950's could draw upon a rich conceptual heritage. Space station designs developed by or under NASA sponsorship during the 25 years since its inception exhibit a relative consistency of concept and purpose. Variations can be attributed to the effects of historical circumstances and advancing technological understanding on an evolving concept of a space station.

The 1920's was a period of extraordinary creativity in the sciences and in architecture in continental Europe. Some examples of that creativity were the space station designs of Hermann Oberth (The Rocket in Interplanetary Space, 1923; design revised in 1929 and 1957), Hermann Noordung (The Problem of Space Flight, 1928), and Baron Guido von Pirquet (articles in Die Rakete, 1928). None of these designers believed that the flight of a manned, permanent station in space was an end in itself. Such an achievement was to serve the more enduring purposes of 1) a greater understanding of the cosmos through celestial observation, 2) service to earth-bound humanity through large-scale meteorlogical observations and global communications, and 3) manned interplanetary exploration through the provision of an earth-orbiting service and logistical station. Two additional purposes -- 4) scientific research in zero-g and remote location laboratories and 5) military defense -- were to be served in Oberth's 1929 design, "Springboard Station." These purposes have remained common to virtually all space station designs proposed since World War II.

The salient design characteristics of these early space station proposals were predicated largely on their purposes. Each design reflected the belief that a space station's functions entailed discrete structural requirements. Astronomical and earth observations required platforms for instruments; scientific research, servicing, and manned planetary exploration required a protected environment for human habitation (which the early designers assumed required simulated gravity); and the space station as a whole would require a power source as well as access by earth-launched logistical vehicles. Thus, Oberth's, Pirquet's, and Noordung's proposals incorporated one or another variation on the principle of modular structure. Power was acquired from the solar rays that warmed the steam boilers of Noordung's "wohnrad," and were reflected to the earth in Oberth's 1923 design. Separate modules housed observatories. Simulated gravity -- not necessary for every space station function -- was to be achieved through the centrifugal force of rotating elements.

The stimulus World War II had given to advances in ballistics and rocketry and the future of man in space was evident as early as 1948 with the appearance of H.E. Ross's and R.A. Smith's space station design (presented to the British Interplanetary Society) and H.H. Koelle's design (presented to the International Astronautical Federation in 1951). These early post-war designs served, as did their predecessors, the purposes of celestial and earth observations, communications, scientific research, and service and refueling bases for extraterrestrial travel. However, Ross, Smith, and Koelle offered more detailed expectations of space station purposes, incorporating such activities as cosmic ray and solar radiation research, radio wave reflection and refraction studies (Ross and Smith); physiological and psychological studies of the effects of space environment on personnel; and investigations into the varying effects of earth and space environments on the properties of solids, liquids, gases, on chemical processes, and on plant life (Koelle). The Ross and Smith and Koelle designs represent continuity not only in the concept of a space station's purposes, but also in its characteristic features; that is, orbital deployment, modular construction, and a rotating habitable element to simulate gravity in crew living and working quarters.

Wernher von Braun's 1952 space station proposal -- his "artificial moon" -- was something of a watershed in the evolution of the space station. As a space station design it embodied one of the prominent design characteristics of most of its predecessors: a rotating element (in this case, a large doughnut shaped structure) centered on a fixed core to achieve both zero-g and simulated gravity. The immediate purpose of his station was to provide a "stop-over" place for a manned trip to the moon, a trip which he felt was beyond the state-of-the-art of any single earth-lunar vehicle. Von Braun's proposal combined enormity of vision with a highly developed appreciation of the capabilities of existing rocketry and technology.

Table 1-2 is a partial list of pre-NASA Space Station concepts and studies.

The important contributions of science and engineering to the defeat of the Axis powers in World War II became one of the more important arguments by which the scientific community successfully persuaded the U.S. Congress to commit the nation to increased support of basic research. The Congress augmented its commitment to the National Academy of Science/National Research Council with the creation of the National Science Foundation in 1950 and the Act to Authorize the Expenditure of Funds Through Grants for Support of Scientific Research in 1958. It reaffirmed the support of scientific research as a legitimate goal of national policy in the National Science and Technology Policy, Organization, and Priorities Act of 1976. Moreover, public opinion polls throughout this period demonstrated that, if the American people did not always understand what scientists were about, they believed that continued public support of scientific research would ultimately benefit the nation. Thus, on the eve of the creation of NASA, the public support of basic science, as well as science applied to the advance of commerce and industry, had accepted objectives of national policy. Those objectives were mirrored in the legislation which brought NASA into being in 1958. Whatever may have been the politics surrounding the creation of NASA, the legislative intent on record was that a national program of aeronautical and space research was justified as an "expansion of human knowledge," and would lead toward "the development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space."

NASA scientists and engineers promptly assumed the role of designing a space station that would best serve the ends of space exploration and travel. NASA space station studies began at Langley Research Center in 1959, culminating in

TABLE 1-2
PRE-NASA MANNED SPACE STATION DESIGN STUDIES
(PARTIAL LIST)

DATE	AUTHOR	DESCRIPTION
1923	HERMANN OBERTH	CONCEPTUAL DESCRIPTION. SUGGESTED MEANS OF SUPPLYING ARTIFICIAL GRAVITY AND BUILDING IN ORBIT.
1928	GUIDO VON PIRQUET	PROVED THAT A SPACE STATION IS AN ENERGY EFFICIENT STEPPING STONE TO OTHER ORBITS, THE MOON AND PLANETS.
1928	HERMANN NOORDUNG	FIRST DESIGN ON PAPER. HEAVY ROTATING SATELLITE WITH SOLAR POWERED GENERATORS. OBSERVATORY POSITIONED AWAY FROM MAIN STRUCTURE.
1948	H.E. ROSS & R. A. SMITH	TWENTY-FOUR-MAN ROTATING SATELLITE WITH MOVABLE ARM. STATION USED FOR OBSERVATION, COMMUNICATION, AND RESEARCH.
1951	WERNHER VON BRAUN	"SPACE WHEEL" CONCEPT ORIGINATED IN CONNECTION WITH "MARS PROJECT." ORIGINALLY 20-SEGMENT WHEEL, LATER CHANGED TO CIRCULAR SHAPED RIM.
1954	KRAFFT EHRICKE	FOUR-MAN ORBITAL STATION WITH MASS CONCENTRATED AT CENTER FOR STABILITY.
1958	KRAMER & BYERS	ENGINEERING DESIGN OF WHEEL-SHAPED ORBITAL STATION BASED ON VON BRAUN'S CONCEPT. INCLUDED AN "ASTROTUG" FOR ASSEMBLING STATION SEGMENTS.

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a symposium held jointly by NASA, the Institute for the Aeronautical Sciences, and the Rand Corporation in 1961. Space station concepts introduced included modular designs evident in earlier proposals and provided both simulated gravity, living and working areas, zero-g platforms for docking and experiments, power plants, and logistical vehicles.

President John F. Kennedy's declaration in May, 1961 that "we should go to the moon" by the end of the decade had significant, albeit sometimes indirect, consequences for the evolution of space station concepts at NASA. The Apollo program diverted most of the agency's energies from space station design to the lunar landing mission. Planning for that mission became the centerpiece of NASA's Manned Spacecraft Center in Houston and Marshall Space Flight Center in Huntsville, even though engineers at Langley Research Center in Virginia continued to work on space station concepts. NASA planners tended to assume that a manned space station in Earth orbit would be a logical and necessary prelude to a manned lunar landing. But once the Agency settled on the lunar-orbit rendezvous as the most "manageable" mode for a manned lunar landing, one of the more immediate reasons for a space station -- a staging and servicing base for earth-lunar flight -- was not necessary. At the same time, the experience acquired during the Apollo program brought about a shift in emphasis in the role of space stations from orbital launch and service bases for extraterrestrial travel, to use as orbiting research facilities. This changing emphasis inevitably altered the design requirements of any eventual space station.

Thus, NASA in-house and contracted space station studies of the 1960's began to emphasize the concept of a space station as a Manned Orbiting Research Laboratory (MORL), or a "research center in space." The MORL studies of 1963-1969 reflected an increased emphasis on the scientific -- or research -- value of a manned orbiting space station. Space science acquired a larger meaning during the 1960's. Not merely astronomy and astrophysics, but geology, hydrology, oceanography, biology, chemistry, nuclear physics, physiology, and materials science became ripe subjects for space-based investigations and laboratory experimentation.

The challenge of developing a space station concept for national defense was taken in 1963 by the Department of Defense, which initiated a Manned Orbiting Laboratory program intended to determine the military usefulness of man in space. As finally designed, the MOL was to have been launched into low Earth orbit by a Titan IIIM booster. A modified NASA Gemini spacecraft would carry a two-man crew into orbit and return them to Earth, while two modules -- a manned laboratory module and an unpressurized test module -- would house and support experiments for the expected 30-day mission. The MOL, however, like NASA's own space station initiative, became a casualty in 1969 of the Administration's efforts to contain the federal budget.

NASA, in spite of the demands of the Apollo program, continued space station design studies throughout the 1960's. Many were conducted by Houston's Manned Spacecraft Center and Huntsville's Marshall Space Flight Center, by both in-house and contractor study teams. Houston concentrated on manned operations, while Marshall centered on an unmanned platform to be serviced periodically. The Spent Stage Workshop, derived from the Saturn V's spent propulsive rocket stage, dominated design efforts at Marshall, while Houston studies were typified by the "Y" configuration "consisting of three radial arms" that, once launched into orbit by a two-stage Saturn V, could be extended to provide living and working quarters for a 24-man crew.

Just as the decision to proceed with a lunar-orbit rendezvous in the early days of the Apollo program was followed by a more detailed consideration of the research function of a manned orbiting space station, experience during the program itself led to the adoption of a configuration for an actual, experimental version of a space station itself -- Skylab. In 1963, the Office of Manned Space Flight (OMSF) had embarked upon post-Apollo planning and by 1965 had settled upon an Apollo Applications Program intended to make full use of the impressive capabilities developed for the Apollo lunar landing mission.

NASA's 1966 agency-wide space station study which emphasized the purposes and objectives of a space station was just one of an array of studies conducted during the 1960's both at NASA's various centers and by major aerospace contractors. Virtually every plausible configuration was scrutinized for its utility in meeting various objectives and for the manner in which it met the mission requirements derived from those objectives.

The 1966 NASA study became the basis of several attempts during the remainder of the decade to win Presidential approval for a NASA space station initiative.

The President's Space Task Group Report of September, 1969, failed to endorse a space station as the necessary "next step" in NASA's development program. Within a year, space station prospects had diminished to the point where NASA believed that its political energies would be better spent on winning approval for a reusable logistic vehicle, the "Shuttle." Nonetheless, NASA space station studies continued well into 1972.

Between 1969 and 1972, NASA carried out Phase B space station studies through contracts with North American Rockwell and McDonnell Douglas along with parallel in-house studies, managed by the Manned Spacecraft Center and the Marshall Space Flight Center. The initial concept, which determined the Phase B Work Statement of April 19, 1969, described the space station as a "centralized and general purpose laboratory in Earth orbit for the conduct and support of scientific and technological experiments, for beneficial Earth applications, and for the further development of space exploration capability."

As it evolved during the early 1970's, the NASA concept of a space station continued to be influenced by external circumstances in several important ways. The political climate of the preceding decade had grown less hospitable to pure science. Many scientists, in turn, believed that NASA's manned space activities not only were unessential to space science, but commanded a disproportionate amount of the nation's modest contribution to scientific research. Science "to the benefit of man," however, still had a substantial constituency, as evidenced by successful efforts in the Congress to develop a national science and technology policy position defined in terms of human betterment.

Thus, while the Work Statement for NASA's 1969 study still spoke of a space station as a "laboratory," little was said in the stated objectives about astronomical or planetary science. Instead, the objectives emphasized "beneficial space applications programs," the study of "long term biomedical and behavioral characteristics of man in space," and the development of operational capabilities for "long duration manned orbiting stations." Lacking strong political support, both NASA's study of a manned flight to Mars by the end of the century and the Space Station failed to obtain White House approval. However, in 1972, development of the Shuttle was approved and the work on Skylab was well underway.

Launched in May, July, and November 1973, four successive Skylab missions placed a workshop in Earth orbit and relayed three three-man crews to conduct experiments in it for record periods of working in space. The orbital workshop was based on conversion of the S-IVB (third) stage of the Apollo launch vehicle into a "dry workshop." The design could be traced to Wernher von Braun's "Project Horizon," a 1959 proposal to use a rocket booster's spent stage as a space station's basic structure, and was similar to Marshall Space Flight Center's 1965-66 Spent Stage Workshop. Skylab was conceived primarily as a research facility, thus continuing an emphasis in space station concepts apparent since the beginning of the Apollo program. The inclusion of the Apollo Telescope Mount (ATM) enhanced Skylab's importance for scientific study of the sun.

The scientific results of Skylab confirmed the concept of a space station as a scientific laboratory. Medical studies conducted during Skylab's several missions demonstrated that "given the proper attention to the appropriate environmental factors," man "adapts rather well to the zero-gravity environment, retaining his ability to function effectively for many weeks .... he can maintain his physical well-being and morale, then readapt to Earth surface conditions with surprising speed." Additionally, Skylab crews and ground support personnel were able "to react to unexpected occurrences on the sun" and were thus "a prime factor in the success of the ATM experiments." Similarly, for the Earth observations program, "a man in orbit, trained to look for objects of interest and alert to unfamiliar features, proved to be of great value to earth scientists in many disciplines." Skylab thus taught two lessons important to the future of manned space stations: (1) That man did indeed have an important role to play in future space-based research and exploration; and (2) that he could adapt for limited periods to a zero-gravity environment.

Space station concepts emerging from NASA in the latter half of the 1970's responded to several important changes in the Agency's environment: 1) The view of some portions of the scientific community which, in a time of apparent diminishing federal support for basic research, believed erroneously that Apollo and Shuttle programs were drawing off funds from unmanned space exploration; 2) the emergence of biological engineering and the synthesis of sophisticated synthetic materials in the laboratory evolving into commercial products; 3) the success of the Skylab program; and 4) the phase-out of the Apollo and Saturn programs and the development of the Space Transportation System with the Space Shuttle.

A shift in emphasis is evident in NASA's 1975 Manned Orbital Systems Concepts (MOSC) study contracted to McDonnell Douglas Astronautics. While the MOSC study still pointed to science and applications research as a purpose of a future space station, emphasis was on the role of manned space activity in solving earth-bound problems such as Earth resources and environmental management and economic and related technological constraints.

With the success of the Shuttle program, it was possible to achieve construction of large structures in orbit. The perceived earlier environmental impediments of zero-g and low-pressure had turned into a positive advantages with the emerging "growth" industries of biotechnology and materials processing. In 1976, NASA's Space Station emphasis shifted toward a space construction base. The key to this change was the concept of space industrialization. Several areas with commercial potential, in which the concept of space industrialization could be applied, were: 1) Space processing and manufacture of materials and pharmaceuticals (e.g., urokinase and silicon ribbon), exploiting the advantages of weightlessness; 2) industrial processing without the risk of thermal pollution; 3) construction of large communications antenna systems to serve such Earth needs as "hazard prediction and warning, search and rescue, electronic mail, and educational and health services," taking advantage of the weightlessness of space; 4) exploitation of uninterrupted availability of solar energy both for space operations and for microwave relay to Earth; and 5) terrestrial observations leading to improved management of forest and water resources and the prediction of environmental changes.

The 1976 space industrialization concept entailed a modular space station design or architecture which incorporated a number of capabilities. A space station serving "space industrialization" would sustain long-term manned operations and permit servicing in orbit. It would also handle "large volumes and masses" as well as provide an operational base for space processing and manufacture. Modularity had become, by now, a common feature of space station designs; henceforth, the basic space station architecture would be planned for modular evolution from an initial deployment of habitation and support system modules to a structure continually growing through the addition of cargo modules and mission modules. The design should permit servicing and supply by the Shuttle orbiter. Finally, the space station could evolve into an orbital depot for Orbital Transfer Vehicles -- manned or unmanned, space-based, reusable vehicles requiring only fuels and payloads to be brought up from Earth for on-orbit refueling and servicing.

In March of 1977, NASA's Administrator announced that NASA planned to begin development of a Space Construction Base in 1980 to be ready for initial use in 1985. By autumn, NASA, through contracts with General Dynamics Convair Division and Rockwell International, began studies of fabricating structural beams in space and the feasibility of a satellite solar power system for sending electrical energy back to Earth. But neither the outgoing Ford Administration nor the new Carter Administration supported NASA's request for $15 million for space station studies in FY 1978.

Cost overruns in the Shuttle program and lack of White House support effectively halted progress toward a space station until 1979 when the Johnson Space Center resumed the effort with a study of the Space Operations Center (SOC). Intended only as an exploration of a concept, the Johnson SOC study examined one similar to that of the earlier "Space Construction Base." The initially deployed core-facility would, when complete, consist of a "self-contained, continuously manned orbital facility built from several shuttle-launched modules," providing in-orbit construction and space flight capabilities.

By April, 1981, Boeing Aerospace Co. had completed the first part of its Phase A (preliminary) definition study for NASA's conceptual Space Operations Center.

Both NASA Administrator, James Beggs, and Dr. Hans Mark, in their 1981 confirmation hearings in June, called for a "permanent," manned space station as the next major step for this country's venture into space. Resolutions calling for a national commitment to a manned, multi-purpose permanent space station were introduced into the Congress by several Congressmen and Senators. Once NASA's new leadership was in place, an Agency-wide space station effort began in earnest with the assignment of Associate Deputy Administrator Philip E. Culbertson to the task of formulating "policy, strategy, and planning of a facility providing the permanent presence of the United States in space."

Table 1-3 summarizes major NASA Space Station milestones and activities.

TABLE 1-3
MAJOR NASA SPACE STATION STUDIES AND ACTIVITIES
(FROM CREATION OF NASA TO CREATION OF THE SSTF)
(PARTIAL LIST)

DATE	AUTHOR	DESCRIPTION
1959	NASA RESEARCH STEERING COMMITTEE	PLACED A SPACE STATION AHEAD OF LUNAR EXPLORATION.
1960	GEORGE LOW	ANNOUNCED PROJECT APOLLO AND INCLUDED SPACE STATIONS WITH THE MANNED LUNAR LANDING.
1961	PRESIDENT KENNEDY	ANNOUNCED THE GOAL OF THE LUNAR LANDING WHICH FOCUSED THE AGENCY'S ENERGIES IN THAT DIRECTION AND AWAY FROM SPACE STATIONS.
1962	LRC SPACE STATION SYMPOSIUM	STATED THE OBJECTIVES OF A LARGE MANNED SPACE STATION.
1966	DOUGLAS AIRCRAFT	MANNED ORBITAL RESEARCH LABORATORY REPORT.
1966	NASA MGT. STUDY, C. DON LAW, E. Z. GRAY	DESCRIBED CONFLICT BETWEEN ARTIFICIAL AND ZERO GRAVITY.
1969	THOMAS PAIN	APPEALED TO PRESIDENT NIXON TO SPONSOR AND FOCUS THE PROGRAM ON THE SPACE STATION.
1969	NASA CENTER DIRECTORS	KEY CONFERENCE ON SPACE STATION -- CORE/ ULTIMATE CONCEPT

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TABLE 1-3
MAJOR NASA SPACE STATION STUDIES AND ACTIVITIEW
(FROM CREATION OF NASA TO CREATION OF THE SSTF)
(PARTIAL LIST)
(CONTINUED)

DATE	AUTHOR	DESCRIPTION
1969-71	ROCKWELL/ MCDONNELL	CONDUCTED PHASE B SPACE STATION STUDIES
1970	CHARLES MATHEWS	REDIRECTED PHASE B EFFORTS AWAY FROM SATURN AND TOWARDS SHUTTLE
1972	NASA	ORIGINAL SPACE STATION TASK FORCE REPLACED BY THE SORTIE LAB TASK FORCE
1973	NASA	LAUNCH OF SKYLAB NOT CONSIDERED A TRUE SPACE STATION
1975	MCDONNELL DOUGLAS	MANNED ORBITAL SYSTEMS CONCEPTS
1976	MCDONNELL DOUGLAS/GRUMMAN	SPACE STATION SYSTEMS ANALYSIS STUDY -- OPERATIONAL BASE AND LABORATORY
1977	ROCKWELL/GD	STUDIES ON BEAM FABRICATION AND SOLAR POWERED SATELLITES
1978	MSFC & JSC	STUDIES ON ORBITAL POWER SUPPLIES AND PLATFORMS
1979	JSC	SPACE OPERATIONS CENTER (SOC)
1980	AEROSPACE CONTRACTORS	EXPLORED SOC CONCEPT
1981	OAST/NASA	ESTABLISHED THE SPACE STATION TECHNOLOGY STEERING COMMITTEE

DSG-799

2.0 MISSION DESCRIPTION

2.1 INTRODUCTION

As the first step in NASA's planning for a potential Space Station system, a major effort was undertaken to define realistic missions that were enabled by or materially benefitted from the permanent presence of man in space. Studies were conducted by NASA advisory boards, in-house panels, and by industry under contract to NASA. Additional studies were undertaken by the international community. The results of these studies, as documented in Book 2, have been integrated into a single time-phased mission set which provides the foundation for current studies of Space Station system architecture. To meet the needs of missions in the science and applications, commercial and technology development areas, the Space Station must be: A research laboratory, an observatory, a service center, a communications and data processing node, a transportation node, a storage facility, and a construction/assembly base.

2.2 MISSION STUDIES AND SYNTHESIS

An informed decision to proceed with development of a U.S. Space Station should rest on well defined needs for such a system. To this end, NASA funded the studies, "Space Station Needs, Attributes, and Architectural Options." In addition, a Space Station Mission Requirements Working Group was established to direct the industry studies and to integrate in-house activities and special studies such as the Space Science Board and Space Applications Board studies. This group was supported by three Mission Area Panels: (1) Science and Applications; (2) Commercial; and (3) Technology Development. The Working Group also maintained liaison with the international community who performed similar studies.

Upon completion of the industry and in-house studies, the Space Station Mission Requirements Workshop was held at the NASA Langley Research Center on May 2-13, 1983. The purpose of the workshop was to review study results and to synthesize the results into a single set of time-phased missions and their associated requirements. In developing this mission set, the following fundamental ground rules were established:

- The mission set must be valid, demonstrated either through a funding commitment as in the commercial case or through endorsement by the scientific community and inclusion in the NASA OSSA long-range plan as in the science and applications case.

- The mission set must be programmatically, scientifically, and technologically realistic.

It is also important to note that the mission set was not restricted to those missions that could only be accomplished on-board a manned Space Station. In fact, the definition of Space Station used here is: The Space Station system includes a manned facility, co-orbiting free flyers and platforms, remote free flyers and platforms, an orbital maneuvering system, a reuseable orbital transfer vehicle, and storage and servicing facilities. Although this total system capability is not expected to be available with the initial Space Station, it is required by the mid-1990's.

The purpose of this summary is to present the results of the study activities discussed above in terms of time-phased mission sets and their associated requirements that must be accommodated by the Space Station. Missions and their requirements will continue to evolve in the months and years ahead.

2.3 TIME-PHASED MISSION SET

The time-phased mission set presented here represents the first step in a continuous activity to develop valid Space Station mission requirements. The next phase of this activity will focus on continued refinement, analysis, and development of the commercial and technology development missions. Further development of the commercial user community is underway at NASA with two contracted studies and the establishment of a NASA in-house team.

The estimate of the potential for commercial materials production is high, but remains to be determined. Extensive Shuttle sortie research will be required prior to 1991 if this potential is to be realized.

There is no single mission or mission area which can justify development of a Space Station. It is the totality of capabilities and auxiliary systems which will satisfy our space needs for the 1990's and provide the gateway to the future in the next century.

The time-phased mission set developed at the Mission Synthesis Workshop, as modified by subsequent analysis, is presented in the following sections.

2.3.1 Science And Applications Missions

The science and applications missions presented in Figure 2-1 are divided into the current NASA disciplines. The code number relates the mission to the NASA data base maintained at the Langley Research Center. This data base includes all pertinent data for the mission currently available. The data base is maintained by the NASA Mission Requirements Working Group and is updated periodically as additional information becomes available. The 21 missions included under Astrophysics range from payloads attached to the Space Station to free flyers at high inclination and/or high energy orbits. The length of the bar denotes the duration of the mission and desired inclination and accommodation are shown. Included in the mission set are free flying missions which will be launched prior to the Space Station era (such as Space Telescope and the Gamma Ray Observatory), but which will be serviced by the Space Station. Others (such as OPEN and Very Long Baseline Interferometer) will not interact with a Space Station at 28.5° inclination but are included for completeness of the total mission set. The triangle in 1991 for the Solar Dynamics Observatory denotes launch with no potential interaction with the Space Station. A number of missions are shown as attached either to the Space Station or to a space platform. Decisions on the location of these missions depend on a number of factors. The dominant factors are the ability to point instruments accurately with acceptable jitter, the degree of contamination of the environment around the Space Station, the frequency of service required by the payload, and the cost effectiveness of the accommodation mode versus the other.

In Earth Sciences and Applications, five missions have been defined. The lidar facility is envisioned as a research facility for development of lidar technology and techniques, as well as scientific studies of the tropical atmosphere. Once the development is complete, lidar instruments would be placed on the Earth Sciences Research Platform located in a polar, or near polar orbit. The Earth Sciences Research Platform is a revolutionary inter-disciplinary facility for study of the Earth, the oceans, the atmosphere, and

FIGURE 2-1
TIME-PHASED MISSION SET - SCIENCE & APPLICATIONS

CODE	NAME	YEAR (1991–2000)
	ASTROPHYSICS	
SAA 0001	SPECTRA OF COSMIC RAY NUCLEI (SCRN)	ATT 28.5° SP/SS
SAA 0002	SPACE PLASMA PHYSICS (ACTIVE)	ATTACHED 28.5° SS
SAA 0002A	SPACE PLASMA PHYSICS (PASSIVE)	ATTACHED 28.5° SP
SAA 0006	STARLAB	ATT 28.5° SP/SS
SAA 0003	SOLAR OPTICAL TELESCOPE (SOT)	ATTACHED 28.5° SP/SS
SAA 0009	PINHOLE/OCCULTER FACILITY	ATTACHED 28.5° SP/SS
SAA 0011	ADVANCED SOLAR OBSERVATORY (ASO)	ATT 28.5° SP/SS
SAA 0004	SHUTTLE IR TELESCOPE FACILITY (SIRTF)	ATTACHED ATTACHED 28.5° SP/SS
SAA 0005	TRANSITION RADIATION & ION CAL (TRIC)	ATT 28.5° SP/SS
SAA 0007	HIGH THROUGHPUT MISSION (HTM)	ATTACHED 28.5° SP/SS
SAA 0008	HIGH ENERGY ISOTOPE	ATT 28.5° SP/SS
SAA 0012	SPACE TELESCOPE (ST)	FREE FLYER 28.5°
SAA 0013	GAMMA RAY OBSERVATORY (GRO)	FF 28.5°
SAA 0014	X-RAY TIMING (XTE)	FF 28.5°
SAA 0019	FAR UV SPECTROSCOPY EXP. (FUSE)	FF 28.5°
SAA 0010	CORONA DIAGNOSTIC MISSION (CDM)	FF 28.5°
SAA 0015	OPEN	FF 0° & 80°
SAA 0016	SOLAR MAX MISSION	FF 28.5°
SAA 0017	ADV X-RAY ASTROPHYSICS FAC (AXAF)	FREE FLYER 28.5°
SAA 0018	VERY LONG BASELINE INTERFERO. (OVLBI)	FREE FLYER 57°
SAA 0020	LARGE DEPLOYABLE REFLECTOR (LDR)	FF 28.5°
SAA 0021	SIRTF SUNSYNCH	FF 97°
SAA 0022	SOLAR DYNAMICS OBSERVATORY	Δ
	EARTH SCIENCE & APPLICATIONS	
SAA 0201	LIDAR FACILITY	ATT 28.5° SS/SP
SAA 0202	EARTH SCIENCE RESEARCH	FREE FLYER 90°
SAA 0203	TOPEX	FREE FLYER 63.4°
SAA 0204	GEOPOTENT RESEARCH MISSION (GRM)	FF 90°
SAA 0205	GOES FOLLOW-ON	Δ

FIGURE 2-1
TIME-PHASED MISSION SET - SCIENCE & APPLICATIONS
(Continued)

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	SOLAR SYSTEM EXPLORATION										
SAA 0101	MARS GEOCHEM/CLIMATOL ORBITER (MGCO)	△ 1990									
SAA 0102	LUNAR GEOCHEM ORBITER			△							
SAA 0103	COMET HMP RENDEZVOUS	△ 1990									
SAA 0104	VENUS ATMOSPHERE PROBE				△						
SAA 0105	TITAN PROBE			△							
SAA 0106	SATURN PROBE								△		
SAA 0107	MAIN BELT ASTEROID RENDEZVOUS						△△				
SAA 0108	SATURN ORBITER								△		
SAA 0109	NEAR EARTH ASTEROID RENDEZVOUS									△	
SAA 0110	MARS SAMPLE RETURN									△	
	LIFE SCIENCES										
SAA 0307	LIFE SCIENCES LAB	PRESSURIZED MODULE (1991–2000)									
SAA 0306	CELSS PALLET			ATTACHED SS (1993–1998)							
SAA 0305	DEDICATED CELSS MOD.									PRES. MOD. (1999–2000)	
	MATERIALS SCIENCE										
SAA 0401	MPS R&D FACILITY	PRESSURIZED MODULE (1991–1995)					Requirements Included in Com 1201				
	COMMUNICATIONS										
SAA 0501	EXPERIMENTAL GEO PLATFORM				△						

biogeochemical cycles. The GOES follow-on is a mission to geosynchronous orbit for development and demonstration of advanced instrumentation in meteorology and climatology.

Solar System Exploration missions are shown as launches and may or may not interact with the Space Station. If a reuseable Orbital Transfer Vehicle (OTV) is available by the mid-1990's, it could be used as a launch stage for some missions. The only mission shown which would be enabled by a Space Station is the Mars Sample Return Mission which requires on-orbit assembly and could use the Space Station for sample analysis on return.

Life Sciences missions have two focii - studies of long duration weightlessness effects on humans, animals, and plants in an on-board lab facility and the development of a fully closed life support system. Initial activities in the Life Sciences Lab are devoted to research on plants, humans, and small animals. Later in the decade (1995) an Animal and Plant Vivarium is added.

The Materials Processing Sciences R & D Facility was identified as a major need by both the Science and Applications Panel and the Commercial Panel. It is shown in both Figures 2-1 and 2-2 for this reason.

The activity envisioned in the Communications area under Science and Applications is an experimental geosynchronous platform which would support a number of communications payloads. This platform could also be a key element in the development of techniques for geoplatform servicing by the combination of the OTV and a "smart" Orbital Maneuvering Vehicle (OMV).

2.3.2 Commercial Missions

The Commercial Mission set is presented in Figure 2-2. The MPS Processing Lab No. 1 is required at the time of initial Space Station capability. A volume of $60m^3$ is required with an average power requirement of 8 kW. It is currently anticipated that this unit would be provided by the Government and used by Government, academic, and industry researchers. MPS Lab No. 2 would probably be provided by the commercial sector. The volume and power requirements for this lab are $60m^3$ and 15kW, respectively.

FIGURE 2-2
TIME-PHASED MISSION SET - COMMERCIAL

MISSIONS CODE	MISSIONS NAME	YEAR (1991 – 2000)
	MATERIALS PROCESSING	
COM 1201	MPS PROCESSING LAB #1	PRESSURIZED MODULE
	MPS PROCESSING LAB #2	PRESSURIZED MODULE
COM 1202	EOS PRODUCTION UNITS	ATTACHED S.S. OR PRES. MOD. OR ATT. S.P.
COM 1203	ECG PRODUCTION UNITS	PRES. MOD. AND ATT. TO S.P. IN 1993 PRESSURIZED MODULE
COM 1206	IEF PRODUCTION UNITS	PRESSURIZED MODULE
COM 1208	DSCG PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1211	VCG PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1213	OPTICAL FIBER PRODUCTION UNITS	PRESSURIZED MODULE
COM 1222	SOLUTION CRYSTAL GROWTH PROD. UNITS	PRES. MOD. OR ATT. SS/SP
COM 1229	IRIDIUM CRUCIBLES PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1230	BIOLOGICAL PROCESSES PRODUCTION UNITS	ATT. S.S. OR PRES. MOD. OR ATT. S.P.
COM 1232	MERGED TECHNOLOGY - CATALYST PROD. UNITS	PRES. MOD. OR ATT. SS/SP
	EARTH & OCEAN OBSERVATIONS	
COM 1014	REMOTE SENSING TEST/DEV./VERIF. FAC.	ATTACHED S.S.
COM 1019	STEREO MULTI-LINEAR ARRAY	LAUNCH; SERVICE; ATTACHED TO SP; SUN-SUNCH ORBIT
COM 1023	STEREO SAR + MLA + CZCS	F.F. SUN-SYNCH

FIGURE 2-2
TIME-PHASED MISSION SET - COMMERCIAL
(Continued)

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	COMMUNICATIONS TESTING										
COM 1105	COMMUNICATIONS TEST LAB			△ ATTACHED S.S. (1993–2000)		△		△		△	
COM 1107	LARGE DEPLOYABLE ANTENNA	REQUIREMENT INCLUDED IN TDM 2210									
COM 1120	LASER COMMUNICATIONS	REQUIREMENT INCLUDED IN TDM 2220									
COM 1127	SPACEBORNE INTERFEROMETER	REQUIREMENT INCLUDED IN TDM 2230									
COM 1128	RFI MEASUREMENTS				□ ATTACHED S.S.						
	COMMUNICATIONS SATELLITE DELIVERY										
COM 1117	PAM-D CLASS SATELLITES				1	2	3	5	4	4	4
COM 1116	PAM-A CLASS SATELLITES				1	2	3	3	3	2	2
COM 1115	IUS CLASS SATELLITES				1	4	6	6	6	7	7
COM 1110	CENTAUR CLASS SATELLITES				1*		1	1	2	2	2
	* REQUIREMENT INCLUDED IN SAA 0501										
	COMMUNICATIONS SATELLITES SERVICING										
COM 1131	PAM-D CLASS SATELLITES										1
COM 1126	PAM-A CLASS SATELLITES								1	1	2
COM 1125	IUS CLASS SATELLITES						1	1	1	2	3
COM 1124	CENTAUR CLASS SATELLITES					1	1	1	1	1	2
COM 1121	RECONFIG. COMM. SAT. SPARES EXCHANGE					2	2	3	3	3	3
	INDUSTRIAL SERVICES										
COM 1304	TELEOPERATOR MANEUVERING SYSTEM (TMS)	POTENTIAL COMMERCIAL OPPORTUNITIES NOT INCLUDED IN MISSION MODEL									
COM 1309	SPACE-BASED REUSABLE OTV										
COM 1312	SATELLITE SERVICING										
COM 1318	MULTI-USE SPACE PLATFORM										

A total of 10 commercial production units are shown for the 1990's. The Electrophoresis Operations in Space (EOS) unit would be provided by McDonald Douglas/Johnson and Johnson and produce a variety of pharmaceutical products. The Electroepitaxial Crystal Growth (ECG) unit provided by Microgravity Research Associates would produce high purity, five centimeter diameter crystals of gallium arsenide. These two activities are currently in the research phase under a Joint Endeavor Agreement with NASA. Additional units with high potential for implementation over the remainder of the decade are:

- Isoelectric Focusing (IEF) - Biological Products;
- Directional Solidification Crystal Growth (DSCG) - Gallium Arsenide, Hg Cd Te and other crystals;
- Vapor Crystal Growth (VCG) - Hg Cd Te and other crystals;
- Optical Fiber - High quality optical fibers;
- Solution Crystal Growth - Crystals with fast switching electronic characteristics;
- Iridium Crucible - High purity iridium crucibles;
- Biological Processes - Proprietary process for production of biological materials; and
- Merged Technology - Catalyst - proprietary process.

It is not expected that all of the above will prove to be successful commercial endeavors. Some will be replaced by new products and processes which will be developed either on Shuttle missions or in the MPS R&D labs.

Analysis of the commercial potential for Earth and Ocean Observations indicates that the return on investment would be adequate for commercial entities to develop and operate instruments, but not adequate for provision of the spacecraft as well. Thus, it is assumed here that instruments would be provided by industry and accommodated on a NASA space platform such as the Earth Science Research Platform. Instruments with the greatest potential are the stereo multilinear array, the stereo synthetic apperture radar, and a coastal zone color scanner type instrument.

The commercial space communications field was the first success in the commercial use of space. Projections of future missions and needs vary widely. The attempt here is to strike a middle ground with an average of 15 satellite deliveries per year divided into the mass categories accommodated by the four upper stages indicated in Figure 2-2. It is assumed here that a cost-effective reuseable OTV introduced in 1994 will begin to provide transportation to geosynchronous orbit and by 1997 will have captured the full 15 missions per year. It appears that a communications test lab attached to the Space Station is required. This is basically an on-orbit antenna test range. Significant technology development is required to move to large antennas for land mobile communication and for laser communications. These activities, while identified by the Commercial Panel, are included under Technology Development Missions for requirements bookkeeping purposes.

With the advent of the OTV, geosynchronous satellite servicing becomes feasible. Thus, servicing missions are shown beginning in 1995 and growing over the remainder of the decade. COM 1121 involves storing a spare direct broadcast satellite (DBS) at the Space Station. Upon failure of an operational DBS, the spare could be rapidly reconfigured to match the failed satellite characteristics and transported to geosynchronous orbit by the OTV. The missions listed under Industrial Services are not missions, as such. They are potential services which industry could provide to the Government and to other industries at a profit.

2.3.3 Technology Development Missions

The Technology Development Missions set shown in Figure 2-3 was primarily developed by the NASA Technology Development Missions Panel. The missions are grouped according to the NASA OAST technology disciplines. In general, the Technology Development Missions require attachment to the Space Station and a large amount of crew extravehicular activity (EVA). Key missions in the materials and structures disciplines are those for development of space construction technology which are enabling for the development of future large antennas both for commercial communications missions and for future science missions. For example, the Large Deployable Reflector Astrophysics mission requires this technology.

FIGURE 2-3

TIME-PHASED MISSION SET - TECHNOLOGY DEVELOPMENT

CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	MATERIALS & STRUCTURES										
TDM 2010	MATERIALS PERFORMANCE TECHNOLOGY	PRESSURIZED MOD. & ATTACHED S.S. (4 Service/yr.)									
TDM 2020	MATERIALS PROCESSING TECHNOLOGY	PRES. MOD. & ATT. S.S.				(1 Service/mo.)					
TDM 2060	DEPLOYMENT/ASSEMBLY/CONSTRUCTION		ATT. S.S.			(1 Service/2 mo.)					
TDM 2070	STRUCTURAL DYNAMICS		ATT. S.S.			(1 Service/mo.)					
TDM 2080	DESIGN VERIFICATION TECHNOLOGY		ATT. S.S.		(1 Service/mo.)				ATT/FF		
	ENERGY CONVERSION										
TDM 2130	WASTE HEAT REJECTION TECHNOLOGY					ATT. S.S.		(2 Service/yr.)			
TDM 2110	LARGE SOLAR CONCENTRATOR TECHNOLOGY						ATT. S.S.		(4 Service/yr.)		
TDM 2120	LASER POWER TRANSMISSION/RECEP./CONV.							ATT. S.S.		(2 Service/yr.)	
	CONTROLS & HUMAN FACTORS										
TDM 2410	ATTITUDE CONTROL TECHNOLOGY		ATT. S.S.		(1 Service/3 mos.)						
TDM 2420	FIGURE CONTROL TECHNOLOGY		ATT. S.S.		(1 Service/3 mos.)						
TDM 2460	TELEPRESENCE & EVA TECHNOLOGY			ATT. S.S.		(1 Service/3 mos.)					
TDM 2470	INTERACTIVE HUMAN FACTORS			PRES. MOD.							
TDM 2430	ADVANCED CONTROL DEVICE TECHNOLOGY				PRES.					PRES.	
	SPACE STATION SYSTEMS OPERATIONS										
TDM 2560	SATELLITE SERVICING TECHNOLOGY	ATT. S.S.	(1 Service/mo.)								
TDM 2570	OTV SERVICING TECHNOLOGY	ATT. S.S.	(1 Service/mo.)								
TDM 2520	HABITATION TECHNOLOGY	PRES. MOD.									
TDM 2510	ENVIRONMENTAL EFFECTS TECHNOLOGY	ATT. S.S.					ATT. S.S.		(6 Service/yr.)		
TDM 2530	MEDICAL TECHNOLOGY	PRES. MOD.									
TDM 2540	POWER SYSTEM TECHNOLOGY EXPERIMENTS						ATT.	(1 Service/mo.)			
TDM 2580	ON-BOARD OPERATIONS TECHNOLOGY			PRES. MODULE							
TDM 2590	PLANETARY AUTOMATED ORBIT OPERATIONS								F.F. W/TMS		

FIGURE 2-3
TIME-PHASED MISSION SET - TECHNOLOGY DEVELOPMENT (CONTINUED)

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	<u>COMPUTER SCIENCE & ELECTRONICS</u>										
TDM 2210	LARGE SPACE ANTENNA TECHNOLOGY			ATT. S.S.		(1 Service/6 mos.)					
TDM 2260	EARTH OBSERVATION INSTRUMENT TECHNOLOGY		PRES. MOD. & ATT. S.S.					(4 Service/yr.)			
TDM 2220	TELECOMMUNICATIONS SYSTEM TECHNOLOGY						ATT.	(1 Service/3 mos.)			
TDM 2230	SPACE INTERFEROMETER SYSTEM TECHNOLOGY					ATT.	(1 Service/3 mos.)				
	<u>PROPULSION</u>										
TDM 2310	FLUID MANAGEMENT TECHNOLOGY	PRES. MOD.									
TDM 2320	LOW THRUST PROPULSION				ATT.	S.S.				(1 Service/2 mos)	
	<u>FLUID & THERMAL PHYSICS</u>										
TDM 2610	FLUID DYNAMICS				PRES. MOD.						
TDM 2620	CRYOGENIC PHYSICS					PRES. MOD.					
TDM 2640	SPACE POLYMER CHEMISTRY					ATT. S.S.		(1 Service/3 mos.)			
TDM 2630	GENERAL RELATIVITY									PRES. & FF	

Although satellite and OTV servicing technology development will be initiated on the Shuttle, this development will continue on the Space Station for several years. As shown in Figure 2-3, most of the technology missions are undertaken over the first half of the decade with a substantial decrease in activity over the latter part of the decade. The time phasing may be overly optimistic, but the technology to be developed early is required for missions in the late 1990's. It may also be short sighted in terms of being able to predict the technology development needs for those missions in 2000 and beyond.

2.4 MISSION REQUIREMENTS

2.4.1 28.5° Space Station

The requirements associated with the time-phased mission set of Figures 2-1 to 2-3 can be summarized in terms of those associated with the manned Space Station and those associated with the co-orbiting platform. Figure 2-4 presents the requirements that the mission set places on the manned Space Station at 28.5°. Placement of the manned Space Station at an inclination of 28.5° is driven primarily by two factors. The majority of U.S. missions considered can be accommodated at 28.5°, and this is the inclination to which maximum payload can be delivered by the Shuttle.

As noted in Figure 2-4, high power is required from the beginning of the station era. 55 kW is required in 1991. The primary driver in power is the commercial materials processing area. In 1991, the two production units and the MPS lab require a total of 43 kW. Intravehicular Activity (IVA) crew time associated with materials processing is also large. The current estimate is that about 1400 crew hours per year is required for each production unit to maximize production and minimize down time. Obviously, the trade-off between crew time and increased automation must be studied in much greater detail to establish the most cost-effective approach to production unit operation. Extravehicular Activity (EVA) hours are primarily driven by the Technology Development Missions and reach a maximum in 1993.

FIGURE 2-4
SUMMARY REQUIREMENTS FOR A 28.5° SPACE STATION

YEAR	MASS KG	PRESSURIZED VOLUME M^3	POWER KW	IVA HOURS	EVA HOURS	# ATTACHED PAYLOADS		# FF SERVICING	# TRANSPORTATION EVENTS
						# PORTS	# PRESSURIZED MODULES		
1991	35,900	195	55	12,300	830	6/2	4(2)[2]	3	--
1992	49,900	195	60	12,900	1,450	13/3	4(2)	3	--
1993[1]	55,000	215	63	16,600	1,520	12/4	5(3)	3	--
1994	61,000	275	88	24,800	1,330	11/4	8(5)	2	4
1995	101,000	275	101	25,200	230	7/4	11(8)	2	6
1996[1]	107,000	310	106	29,500	160	10/4	14(10)	2	12
1997	101,000	305	121	30,200	150	8/4	14(10)	1	10
1998	99,000	305	112	27,400	140	5/4	14(10)	2	13
1999[1]	96,000	370	130	27,500	110	2/2	15(10)	2	14
2000	94,000	365	129	26,900	70	2/2	15(10)	2	14

(1) EEG PRODUCTION FACILITY ADDITIONAL UNITS BROUGHT ON LINE IN 1993, 1996, AND 1999 ARE ASSUMED TO BE CO-ORBITING FREE FLYERS

(2) NUMBER IN PARENTHESIS IS THE NUMBER OF COMMERCIAL PRODUCTION UNITS PROVIDED BY INDUSTRY

Note that this is actual work time and does not include the time associated with getting into and out of the suit and associated preparation time. The number of pressurized modules is largely due to commercial production units. Free flyer servicings are those servicings associated with science mission free flyers at 28.5° inclination.

Transportation events are those activities involving use of the OTV to transport payloads to geosynchronous orbit or to provide servicing to those spacecraft. It is assumed, as noted previously, that the OTV becomes available in 1994. In addition, up to three spacecraft are assumed to be transported to geosynchronous orbit on a single OTV flight.

The summary requirements for the co-orbiting 28.5° platform are given in Figure 2-5. These requirements are associated with U.S. science payloads. Accommodation of international instruments, while not shown in this Figure, is clearly a possibility as noted in the results of the parallel international utilization studies. The number of servicings per year indicated in Figure 2-5 is based on the need for payload interchange and servicings and require use of the OMV to either bring the platform to the proximity of the manned station or to transport the payload to the platform for exchange.

2.4.2 International Space Utilization

Parallel studies of space utilization have been undertaken by the international community. These initial studies have been completed recently and are summarized here only in broad terms. The European Space Agency (ESA), Japanese, and Canadian results are summarized in Table 2-1 and compared with U.S. use in Table 2-2. Table 2-1 is self-explanatory and will not be discussed further here. As noted in Table 2-2, a manned R&D lab for Materials Science and Space Processing is required from the viewpoint of all countries. Fundamentally, all the countries note a substantial role for a manned Space Station in both Science and Applications and Technology Development. Operational support to unmanned facilities is also viewed as a major Space Station role.

Although U.S. requirements for the low inclination platform are relatively modest, as noted in Figure 2-5, the international community also sees a need

FIGURE 2-5
SUMMARY REQUIREMENTS
FOR A 28.5° CO-ORBITING PLATFORM

YEAR	POWER KW	RECORDING DATA RATE MBPS	# ATTACHED PAYLOADS	PAYLOAD MASS KG	# SERVICINGS
1991	2.5	16	2	6,400	2
1992	3.1	66	3	11,500	3
1993	4.7	67	4	18,500	2
1994	1.9	50	2	12,400	3
1995	3.2	51	3	19,400	2
1996	3.3	51	2	16,600	3
1997	2.6	2	3	16,600	3
1998	2.6	2	3	16,600	2
1999	4.9	44	3	25,500	3
2000	2.6	42	1	12,500	2

TABLE 2-1
INTERNATIONAL SPACE UTILIZATION

ESA (128 Payloads)	JAPAN	CANADA (37 Payloads)
MATERIAL SCIENCE AND SPACE PROCESSING - AUTOMATED PROCESSING FACILITY (20 KW) - MANNED R&D FACILITY (10 KW) LIFE SCIENCES - FREE FLYER (EURECA) - MANNED R&D FACILITIES (SHORT AND LONG MODULES) SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, FREE FLYERS, AND PLATFORM (57 DEGREES TO POLAR) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS, AND PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - ASSEMBLY/CONSTRUCTION - SATELLITE SERVICING NEW FIELDS - CALIBRATION LAB - MODULAR OTV - SOLAR ENERGY TRANSMISSION - SPACE PROPULSION SYSTEM DEVELOPMENT - SPACE DEBRIS REMOVAL	MATERIAL SCIENCE AND SPACE PROCESSING - MANNED R&D FACILITY - PROCESSING FACILITY LIFE SCIENCES - MANNED R&D FACILITY (BIOLOGY, SPACE MEDICINE, CELSS) SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, MANNED AND UNMANNED FACILITIES (NEAR POLAR) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS/ PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - FREE FLYER FOR SPACE PLASMA, ADVANCED PROPULSION, MICROWAVE ENERGY TRANS- MISSION, SOLAR ARRAYS AND CONCENTRATORS - ATTACHED MODULE FOR LARGE STRUCTURES, LONG DURATION EXPOSURE, ZERO GRAVITY LIQUID HANDLING COMMUNICATION TECHNOLOGY - LARGE ANTENNAS CONSTRUCTION - SATELLITE ASSEMBLY AND TEST - MAINTENANCE	MATERIAL SCIENCE AND SPACE PROCESSING - MANNED R&D FACILITY - AUTOMATED PROCESSING FACILITY LIFE SCIENCES - MANNED R&D FACILITY SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, FREE FLYERS/ PLATFORM (SUN SYNCHRONOUS, 4-7 KW, 120-240 MBPS) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS/ PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - LARGE STRUCTURES CONSTRUCTION/ASSEMBLY - SOLAR CELLS/ARRAYS - SENSOR DEVELOPMENT - OTV SRM - MAINTENANCE, SERVICE, REPAIR

TABLE 2-2
INTERNATIONAL SPACE UTILIZATION SUMMARY

MISSION AREA	U.S.	ESA	JAPAN	CANADA
MATERIAL SCIENCE AND SPACE PROCESSING				
MANNED R&D LAB	●	●	●	●
ATTACHED PROCESSING FACILITY	●			
CO-ORBITING PROCESSING FACILITY	●	●	●	●
LIFE SCIENCE				
MANNED R&D LAB	●	●	●	●
CO-ORBITING RES. FACILITY				
SPACE SCIENCES AND APPLICATIONS				
EARTH OBSERVATION				
HIGH INCL. FF/P	●	●		●
ATTACHED RES.	●			
MANNED HIGH INCL.			●	
ASTRONOMICAL OBSERVATION				
ATTACHED OBS.	●			
LOW INCL. FF/P	●	●	●	●
HIGH INCL. FF/P	●	●	●	●
TECHNOLOGY AND OPERATIONS				
LARGE STRUCTURES	●	●	●	●
ENERGETICS	●	●	●	●
SENSOR DEVELOPMENT	●			●
MAINTENANCE/SERVICE/REPAIR	●	●	●	●
OTV	●	●		●

for such a platform for astronomical observations. Japan sees a need for a manned facility at high inclination primarily to support real-time oceanographic applications. Although the U.S. is the only country calling for an attached MPS processing facility, the European Columbus study focuses on a Spacelab derivative system which can operate either in an attached or co-orbiting mode.

2.4.3 Special Requirements

Each mission area has its own special requirements that will impact the Space Station design. Science and applications missions, whether Earth observations or astrophysical, require stringent control of the contamination environment around the Space Station which are instrument dependent. These requirements are defined in more detail for representative instruments in the Mission Synthesis Workshop Report. These missions also require highly accurate pointing and stability.

Commercial missions may require both physical and communications security for proprietary processes and/or experiments. Rapid replacement of direct broadcast satellites in geosynchronous orbit requires the capability for on-orbit storage of complete spacecraft. Finally, the materials processing facilities require storage of both raw materials and spare equipment.

Technology Development Missions are unique in their requirement for large amounts of EVA time. A corollary to this requirement is the need for improved suits, tools, and techniques to maximize man's productivity in extravehicular activities.

2.5 SPACE STATION FUNCTIONAL CHARACTERISTICS

To meet the requirements associated with the time-phased mission set presented in Figures 2-1 to 2-3, the Space Station must have the following characteristics: Initially, the manned element placed at 28.5° must function as a research laboratory, an astrophysical observatory, a service center (which requires basing and support of an OMV), and as a communications and data processing mode (for on-board and co-orbiting experiments). In addition, both low and high inclination platforms are required.

By the middle of the 1990's, the manned element must additionally serve as a transportation node with a space based OTV, provide storage for complete spacecraft and serve as a construction and assembly depot for construction of spacecraft larger than those that can be accommodated in the Shuttle Orbiter cargo bay.

By the year 2000, enhanced capability in all areas will be needed as the traffic induced by the existence of the Space Station, with the characteristics described, places increased demands on Space Station services. Modest replication of the manned element (3 to 4 person) in near polar orbit by the year 2000 is the earliest expectation of this capability.

2.6 USER CONCERNS AND NASA CHALLENGES

Many elements of the user community have concerns about the Space Station. The three most prevalent concerns are listed below:

(1) How will NASA insure "user friendliness?"

- Rapid and guaranteed access;
- Adequate resources (including storage);
- Minimum "red tape";
- Security for proprietary experiments, processes, and data;
- Contamination and pointing control; and
- Reasonable user charge policy.

(2) How cost effective are:

- Satellite/platform servicing; and
- Space based OTV.

(3) Will Space Station development reduce funding available for traditional space science and applications disciplines?

As a result of these concerns, a list of challenges to NASA as it proceeds with its Space Station planning activity can be developed. The list below should be considered as representative and neither exhaustive nor necessarily endorsed by the entire user community.

- Interface Philosophy - keep it standard and simple;
- User Charge Policy - establish it early and stick to it;
- Establish a user counterbalance to the designers/builders - don't weaken the user accommodation impetus;
- EVA is necessary - establish the equipment, tools, and techniques early and get on with development, test, and training on Shuttle;
- High productivity is the key to cost effectiveness - excessive management and ground control is the enemy of productivity;
- The right mix of automation and crew is essential and must be established early;
- To attract business, the Space Station must be resource rich;
- Satellite/platform servicing and OTV operations must be cost effective;
- On-board research labs should be equipped and operated like ground research labs; and
- Spare parts must be available when needed.

3.0 SPACE STATION SYSTEM REQUIREMENTS AND CHARACTERISTICS

3.1 INTRODUCTION

The Space Station is a low Earth orbit facility that will operate with complementary, interfacing space systems to support various manned and unmanned space operations beginning in the early 1990's. While the specific missions to be performed or supported from the Space Station are not yet defined, the general nature of the missions as discussed in the preceding section is sufficiently understood to begin identifying the top-level systems requirements for the program. Table 3-1 presents a set of general features of a Space Station that should be expanded as the Space Station system evolves. The following are examples of top-level requirements and characteristics being considered and evaluated.

3.2 MISSION-SPECIFIC REQUIREMENTS

Mission-specific requirements were derived from synthesis of the various mission objectives. Requirements in this category are key drivers in the Space Station design and include such factors as orbit selection (altitude and inclination), electrical power requirements, mission durations, attitude control (pointing) accuracy, thermal control requirements, environmental factors (e.g., contaminants, microgravity levels), communications and data management, and crew requirements. These requirements were developed within the context of the Mission Requirements Working Group.

3.3 USER INTERFACE REQUIREMENTS

The Space Station system design, integration, and operation shall be user oriented to the maximum extent possible, consistent with safety, legal, and budgetary constraints. This requirement implies flexibility and simplicity of user interface systems and documentation.

Experiment/payload operations at the manned station and within the system shall include a high level of user participation.

TABLE 3-1

SPACE STATION GENERAL FEATURES

- Shall assume a phase C/D start by or before FY 1987 to support a flight in the early 1990's.
- Will be in low Earth orbit (LEO).
- Will be shuttle-compatible for delivery, assembly, and disassembly.
- Shall be a manned system.
- Will be supported by the Shuttle, initially on 90 day cycles.
- Shall provide for non-hazardous, planned disposal at the end of useful life of subsystems and components.
- Shall have a design goal for indefinite life through on-orbit maintenance, repair, or replacement.
- Shall have modular-evolutionary design that permits growth and accepts new technology.
- Shall provide a time-phased capability to accommodate mission needs and requirements.
- Shall consider both the initial development cost and life-cycle costs as a design driver.
- Shall be user-oriented to the maximum extent possible implying flexibility and simplicity of user interface systems and documentation.
- Shall have a design goal of commonality for hardware/software of identical or similar functions in terms of systems, subsystems, and interfaces.
- Shall incorporate on-orbit autonomous operations to minimize crew and/or ground involvement as a design driver.
- Shall provide for a safe-haven and/or escape capability from the Space Station.

The Space Station system and its operations shall provide simple, standard, stable requirements and interfaces for users of its services. The Space Station system shall be compatible with payloads providing their own services, such as computational, communications, environmental control and life support, and/or power subsystems.

Operations and design shall provide a system to facilitate on-board operations by scientists or payload experts with a minimum of Space Station specialized training.

A capability shall be provided for independent user operation and monitoring of payloads consistent with safety and user-compatibility constraints.

Flight and ground data systems supporting payloads shall be transparent to the users. Space Station housekeeping and engineering data transmitted to the ground will be functionally separate from the payload science data.

Payloads requiring secure command and data handling will be responsible for command and data encryption and decryption within the payload and on the ground.

3.4 SYSTEM REQUIREMENTS

The following is a summary of top-level system requirements:

3.4.1 Safety

The Space Station system shall provide for a "safe-haven" and/or escape capability. In addition, the Space Station shall be designed in the following order of precedence to: (1) Eliminate hazards by removal of hazard sources and operations; (2) reduce hazards by selection of least hazardous design or operations; (3) minimize hazards by safety factors, containment provisions, isolation techniques, purge provisions, redundancy, backup systems, work-arounds, EVA, safety devices, caution and warning devices, and procedures; and (4) minimize hazards through a maintainability program and adherence to an adequate maintenance and repair schedule.

3.4.2 Maintainability

Subsystems shall be designed to permit repair and/or replacement at the orbital replacement unit (ORU) level. To effect the desired maintenance, the Space Station shall include facilities and equipment for on-orbit monitoring, checkout, storage, replacement, repair, and test of subsystem hardware. Critical systems shall be capable of undergoing maintenance without the interruption of critical services and shall be "fail safe" while being maintained.

3.4.3 Reliability

Space Station critical components, subsystems, and/or systems shall be designed to be fail-operational/fail-safe/restorable as a minimum. Mission critical components, subsystems, systems, and/or critical ground support hardware shall be designed fail-safe; other hardware shall be designed to be restorable. Redundant functional paths of subsystems and systems shall be designed to permit verification of their operational status in flight without removal of ORU's. Subsystem design shall provide redundancy management and redundancy status to the crew.

3.4.4 Operating Life

The Space Station shall have the ability to remain operational indefinitely through periodic maintenance and replacement of components. To this end, all subsystems shall be designed for modular-growth, on-orbit assembly, disassembly, and replacement and on-orbit repair and maintenance. All subsystems shall have a specified ten year design life minimum requirement using maintenance as necessary.

3.4.5 Growth Buildup

The Space Station shall permit progressive buildup to higher orders of capability. Where technology changes are anticipated to provide economical growth in capability, the initial hardware and software shall be capable of being replaced or integrated with the higher technology systems as they become available.

3.4.6 Autonomy

Autonomy shall be incorporated in system and subsystem design to minimize crew and/or ground involvement in system operation.

3.4.7 Environments

The Space Station shall be designed to meet all performance requirements in natural and induced environments in which it must operate.

3.4.8 Systems Verification

Verification of the Space Station system will be accomplished by a combination of analyses and ground and flight tests.

3.4.9 Logistics

An integrated logistics requirements plan shall be defined and implemented to assure effective and economical logistics support of the development, verification, activation, and operational phases of the Space Station Program.

3.4.10 Quality Assurance

An effective program for quality assurance shall be implemented that validates the acceptability and performance characteristics of conforming articles and materials to assure the detection and correction of all departures from the design and performance specifications. These quality assurance provisions apply to all ground development and verification testing as well as all on-orbit maintenance activity.

3.4.11 Commonality

Hardware, software, and technology commonality shall be applied to elements, modules, submodules, and subsystems within the Space Station to enhance standardization for direct interchangeability and to assure compatibility and minimize program development costs. Commonality goals should be applied for structural, electrical, and fluid subsystems for all Space Station system elements.

3.4.12 EVA Provisions

The Space Station design shall include provisions for performing extravehicular activity (EVA).

3.4.13 Cabin Atmosphere

The Space Station crew environments shall be a shirt-sleeve, two-gas atmosphere (nitrogen-oxygen). The cabin pressure shall be selected to facilitate productive EVA with no pre-breathing or other operational constraints.

3.4.14 Crew Accommodations

Accommodations shall be provided for the Space Station crew which carefully consider both habitability and health maintenance as well as other factors which will maintain the crew at peak effectiveness.

3.4.15 Orbit Management

Space Station design shall include provisions for maintenance of desired orbit characteristics with unique propulsive capability.

3.4.16 Resupply Interval

The Space Station shall be able to operate with a full crew complement without resupply for a nominal period of 3 months. Contingency servicing or resupply shall also be provided as required. All resupply systems shall be designed so that they can be delivered and retrieved by the Space Shuttle Orbiter. Space Station waste products shall also be returned to Earth by the Orbiter.

3.4.17 System Disposal

The Space Station should have provisions for non-hazardous disposal of its modules, equipment, elements, etc., and/or the total station at the end of its useful life.

3.4.18 Communications

The Space Station communications system shall be capable of command and two-way voice, telemetry, and color video communications within the Space Station, with the ground, and with other interfacing elements of the Space Station system as required. The Space Station shall be capable of communication by relay through the TDRSS communication satellite system. Provisions shall also be made for secure communications to be provided by the user requiring such security.

3.4.19 Information System

The design of the Space Station information system shall be compatible with the overall program integrated data network with which it shall interface in providing efficient data and information handling, processing, and transmittal to the user communities, as appropriate. The information system shall be "user transparent" (i.e., users should not be forced to deal with the complexity of the embedded system).

3.5 SUBSYSTEM REQUIREMENTS

The Space Station requires the functions of the following subsystems:

- Structures;
- Mechanisms;
- Electrical power;
- Thermal control;
- Environmental control and life support;
- Information and data management;

- Communications and tracking;
- Guidance, navigation, and control;
- Propulsion;
- Crew systems and crew support;
- Extra-vehicular activity (EVA);
- Intra-vehicular activity (IVA);
- Health maintenance; and
- Fluid management.

3.6 OPERATIONAL REQUIREMENTS

3.6.1 Space Station Buildup

The Space Station will initially be deployed and serviced by the Space Shuttle. Operations leading to permanent manning of the station will include Shuttle-tended, on-orbit placement, deployment and test, and unmanned initial operations. Manning will occur after the system is verified and will consist of a crew of TBD, nominally rotated by the Space Shuttle every TBD days. Expendables and spares will be carried to the Space Station and will be replaced periodically by the Space Shuttle. As the Space Station expands to include additional habitat volume, the crew size will have the capacity to increase to a level of TBD Space Station crew members.

3.6.2 Orbital Operations

Orbital operations will include operating and servicing attached and unmanned platform-mounted experiments/facilities, servicing payloads and satellites, test and deployment of payloads and upper stages, national security operations, and eventual large-scale construction of space structures. The Space Station will operate cooperatively with the unmanned platforms with their attached instruments, experiments, and facilities by providing systems monitoring and control, data and material collection, and systems/instrument replacement, refurbishment, and servicing.

3.6.3 Ground Operations

The Space Station will be controlled from the ground by the Space Station control center during unmanned periods. During manned operations, the ground will act in a monitoring mode but will be responsible for developing long-range mission timelines for the Space Station crew.

3.6.4 Cost-Effectiveness Considerations

The Space Station system will be designed with the intent to minimize operations-driven costs and to maximize effectiveness for the users. Systems will be designed to include an appropriate degree of autonomy and automation to be easily monitored and maintained on orbit without interruption of critical services.

3.7 DEVELOPMENT AND BUILDUP CHARACTERISTICS

The Space Station and its interfacing elements shall provide phased development and capability buildup in a manner to fulfill mission requirements on a time-phased basis. The Space Station design shall provide phased increase in capability that can be matched to demand for space-based services. Each program phase shall establish a significant increase in U.S. manned space capability and should be justifiable on a stand-alone basis if necessary. Modularity at both the element and subsystem level shall be emphasized as a means of accomplishing this flexibility and accommodating budget constraints.

3.8 ELEMENT INTERFACE REQUIREMENTS

The Space Shuttle shall be utilized for the launch of Space Station elements and for crew and resupply logistics. Space Shuttle operational and performance capabilities projected for the 1990's shall be utilized for initial Space Station system definition purposes.

The Space Station will provide TBD structural, electrical, data management, thermal control, communications, and crew services required by attached science and applications laboratories.

The Space Station will provide the capability for space basing orbit transfer systems. Based on programmatic and budgetary considerations, initial orbit transfer systems may employ expendable vehicles and associated systems.

Certain mission objectives may require use of co-orbiting satellites and unmanned platforms. The Space Station must, therefore, provide appropriate interface systems for communications and tracking, satellite deployment, retrieval, servicing, data management, and other TBD service areas.

The Space Station shall also provide the capability for servicing other non-co-orbiting satellites through use of the Orbital Transfer Vehicle (OTV).

The Space Station shall also provide interface systems for conducting orbital assembly and construction of space systems.

4.0 ADVANCED DEVELOPMENT PROGRAM

4.1 INTRODUCTION

The Space Station's desired operational characteristics can be summarized to include indefinite on-orbit presence, accessibility via the Space Shuttle, permanently-manned occupancy, the ability to be maintained and repaired in space, built-in growth potential, and user accommodating. These characteristics are being used to define technical design requirements and criteria for the system. Assessments of these requirements by NASA's Space Station Technology Steering Committee (SSTSC), the Concept Development Group, and representatives from industry led to the conclusion that the current state-of-the-art technology in selected disciplines is inadequate to permit building the Space Station without compromising some of its desired operational characteristics. However, it was felt that appropriate technological advancements could be forthcoming with proper emphasis and investment. Therefore, technology will play a prominent role in determining both the initial and future Space Station capability and utilization.

The challenge posed by the Space Station is to develop technologies that are critical to the initial Space Station configuration without obviating the application of advanced technologies in the evolutionary growth elements of the system. Evolution implies not only growth of the physical plant, but also increases in system performance, capability, and complexity.

The proposed Space Station design and development start date in FY 1987 allows several years in which to mature new technologies for application in the initial system and, subsequently, in its evolutionary growth configurations. The approach being taken by NASA to develop and demonstrate technology for the Space Station builds upon the Agency's strong generic research and technology (R&T) base program. Through assessments of the R&T program, high potential technologies have been identified that are relevant to a Space Station application and have the potential to enhance or enable the desired operational system. From these, specific technologies are being selected for advanced development based on their potential and maturation forecast. In this context, advanced development implies a process whereby generic technologies are focused to a Space Station application and matured to a brassboard/prototype level in order to demonstrate their feasibility, establish their performance, and quantify the risk (cost and schedule) associated with their inclusion in the Space Station development phase. Book 4 describes the planning and implementation activities associated with developing technology for the Space Station Program.

4.2 GENERIC TECHNOLOGY BASE

In anticipation of a Space Station initiative and in recognition of the role that technology might play in its design, NASA management commissioned the Space Station Technology Steering Committee (SSTSC) in the Fall of 1981 to provide guidance for the initiation and implementation of technology development programs. The SSTSC formulated the following set of objectives to guide their activities:

- Establish the desired level of technology to be used in the initial design and operation of an evolutionary, long-life Space Station and the longer term technology to be used for later application for improved capabilities. Initial technology should be available by approximately 1986 to support a Space Station launch in 1990.
- Assess the level of technology that will be available from the current base R&T program which will be applicable to a Space Station.
- Plan, recommend, and monitor a program to move the current technology to the level stated above.
- Identify, evaluate, and recommend opportunities to utilize the Space Station as an R&T facility.

Their assessments, including industry participation at the Williamsburg Technology Conference in March of 1983, resulted in a set of recommended advanced technologies which should be matured to support the initial Space Station and its evolutionary configurations.

Within NASA, the Office of Aeronautics and Space Technology (OAST) has the primary responsibility for conducting the space research and technology (R&T) program including programmatic emphasis to advance the generic technology base. Other NASA offices (e.g., Space Science and Applications, Space Flight, and Space Tracking and Data Systems) also conduct advanced technology application activities that contribute to and strengthen the space R&T program. The space R&T program provides the base from which specific new technologies are being selected for advancement based upon their potential for enhancing the design and implementation of the Space Station.

4.3 ADVANCED DEVELOPMENT PROGRAM

A programmatic distinction will be made between the generic space R&T program and the Advanced Development Program which provides for focusing generic technologies to a Space Station application. The Advanced Development Program is to be funded under the aegis of the Space Station Program and consists of the following key elements: Focused technology, prototype technology, test beds, and flight experiments.

4.3.1 Focused Technology

An objective of the Advanced Development Program is to provide a portfolio of new technologies that can be used in the design of the Space Station. A set of these potential technologies at various levels of early maturity have been identified in the generic R&T base. However, without continued funding and emphasis, it is possible that many of these will not make the "gate" (i.e., be factored into the initial or subsequent designs of the Space Station). There are several reasons why this may happen. First, the technologies within the generic base activity do not normally reach levels of maturity that clearly establish feasibility and risk for a specific application. Lack of funding and clear requirements are common impediments. Second, due to a lack of demonstrated maturity, the system designer is driven to select technology from the existing state-of-the-art because program time lines cannot accommodate schedules for proof-of-concept demonstrations or because there is an unwillingness to accept the risk associated with new but relativey immature technology. A third constraint hindering the transfer and use of advanced technology is often associated with the lack of "technology awareness" by system developers.

Therefore, the initial activity element of the Advanced Development Program is to ensure that a clear and proper application focus is provided to the generic

R&T base program and that the necessary funding is provided to continue technology development through demonstration at the breadboard level. These activities constitute "focused technology".

4.3.2 Prototype Technology

Once the generic base technologies have been focused to the Space Station application and their maturity has been demonstrated for feasibility by the technologists in the laboratory, decisions to continue the development process into prototype components and subsystems can be made. These decisions will be based upon assessments of the maturity that individual technologies must achieve to become viable options for application in the design of the Space Station system. These assessments will include consideration of technical complexity, development risk, potential benefit, and perceived need.

It is through this element of the Advanced Development Program that advocacy and funding will be provided for developing prototypical hardware that embodies the advanced technologies. Once developed, this hardware will be integrated into subsystems and cycled into dedicated test beds for final test and evaluation. It is through the joint participation of technologists and system developers that the transfer of technology to the Space Station program will occur or at least be facilitated.

4.3.3 Test Beds

The prime objective of the Advanced Development Program is to advance the state-of-the-art technology to provide greater opportunities to enhance system performance, reduce life-cycle costs, and facilitate evolutionary changes to the operational system as desired. Fundamental to the success of this program are plans to implement general test bed capabilities in which new technologies, techniques, and approaches can be tested at the brassboard or prototype level of development. The general aspect is critical to the test beds because they must provide sufficient flexibility to accommodate a variety of technical approaches throughout the life of the Space Station program.

It is now planned that the test beds will be implemented along major Space Station subsystem disciplines. The initial test beds include: Data Management System; Environmental Control and Life Support System; Power System, Thermal System; Attitude Control and Stabilization System; Auxiliary Propulsion System; and Space Operations Mechanisms. Other test beds will be developed as appropriate.

Management responsibility for each of the test bed activities will be assigned to individual NASA Field Centers recognizing that specific elements of each test bed capability may reside at different locations. In planning, coordinating, and implementing their respective program, these Centers will be responsible for enlisting the participation and support of other NASA Centers based upon expertise and related activities to ensure that a smooth transition occurs (i.e., technology transfer).

4.3.4 Flight Experiments

Although the test bed approach will be primarily manifested in ground-based facilities, the need for selected flight experiments and demonstrations in the space environment using the Shuttle is recognized and will be implemented as part of the Advanced Development Program.

The purpose of this activity is to use the unique space environment provided by the Space Shuttle to validate the performance of critical components and subsystems which cannot be validated in ground tests, in order to verify and quantify calculated performance, to identify unforeseen anomalies, and to update engineering design criteria. It will also demonstrate techniques, sensors, tools, and procedures required for Space Station control, maintenance, and repair and servicing operations. The approach will be to identify candidate flight experiments and demonstrations, develop integrated plans including resources and schedules, and coordinate with other NASA elements conducting Shuttle flight experiment programs.

4.4 MANAGEMENT RELATIONSHIPS

The management relationships for implementing and controlling the Advanced Development Program are depicted in Figure 4-1. The Level A program office will provide management coordination with the external offices involved and establish overall guidelines and controls. The Space Station Technology Steering Committee (SSTSC) will serve as an advisory group to Level A. Program implementation and procedures will be covered by a Level A program directive. This directive will address only those activities falling under the funding cognizance of the Space Station Program.

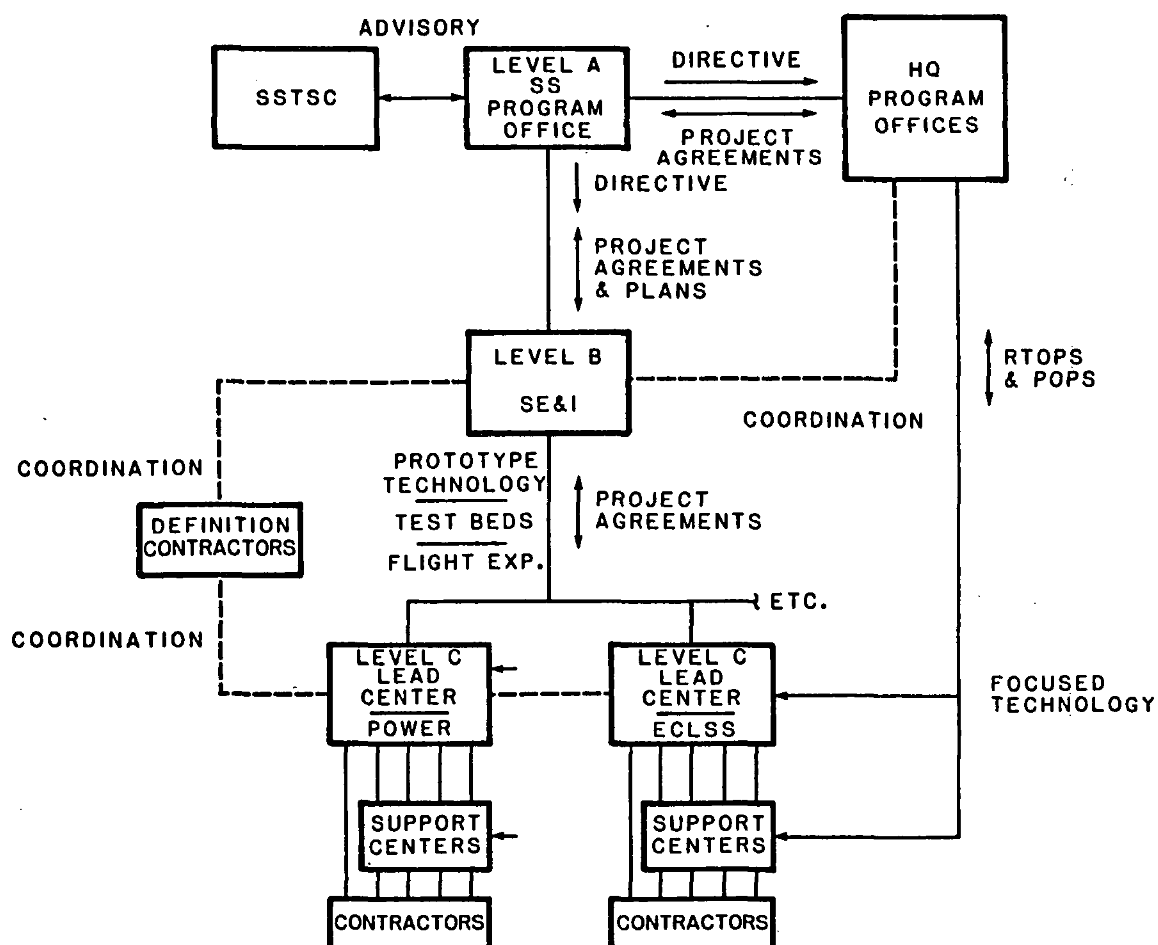
The Level B program office, through the Systems Engineering and Integration function, will coordinate all program technology development and ensure that program emphasis is placed on those areas most critical to Space Station development. Level B will also coordinate the use of all test beds to insure maximum utility to the program.

The Level C Lead Centers (and teams) for the technology areas will coordinate the focused technology activity, as negotiated with appropriate Headquarters offices, through established mechanisms (i.e., RTOPs and POPs). The Level C lead centers will be responsible for the other advanced development elements (prototype technology, test beds, and flight experiments) with funding and control established through normal program channels.

Appropriate program/management plans will be prepared to document the advanced development activities. These activities will be scheduled to support both the initial and the evolutionary Space Station.

FIGURE 4-1

SPACE STATION PROGRAM ADVANCED DEVELOPMENT PROGRAM MANAGEMENT RELATIONSHIPS



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5.0 SYSTEM DEFINITION

5.1 INTRODUCTION

Book 5 is not published as an individual document although the system concepts and consideration that were derived are reflected in other volumes of the Program Description Document (i.e., Book 2, 3, and 6). A summary is presented here to review various aspects of Space Station system architecture and some of the system design considerations. More detailed system and configuration trades and preliminary designs will be the subject of the initial procurement that is planned for the program definition phase.

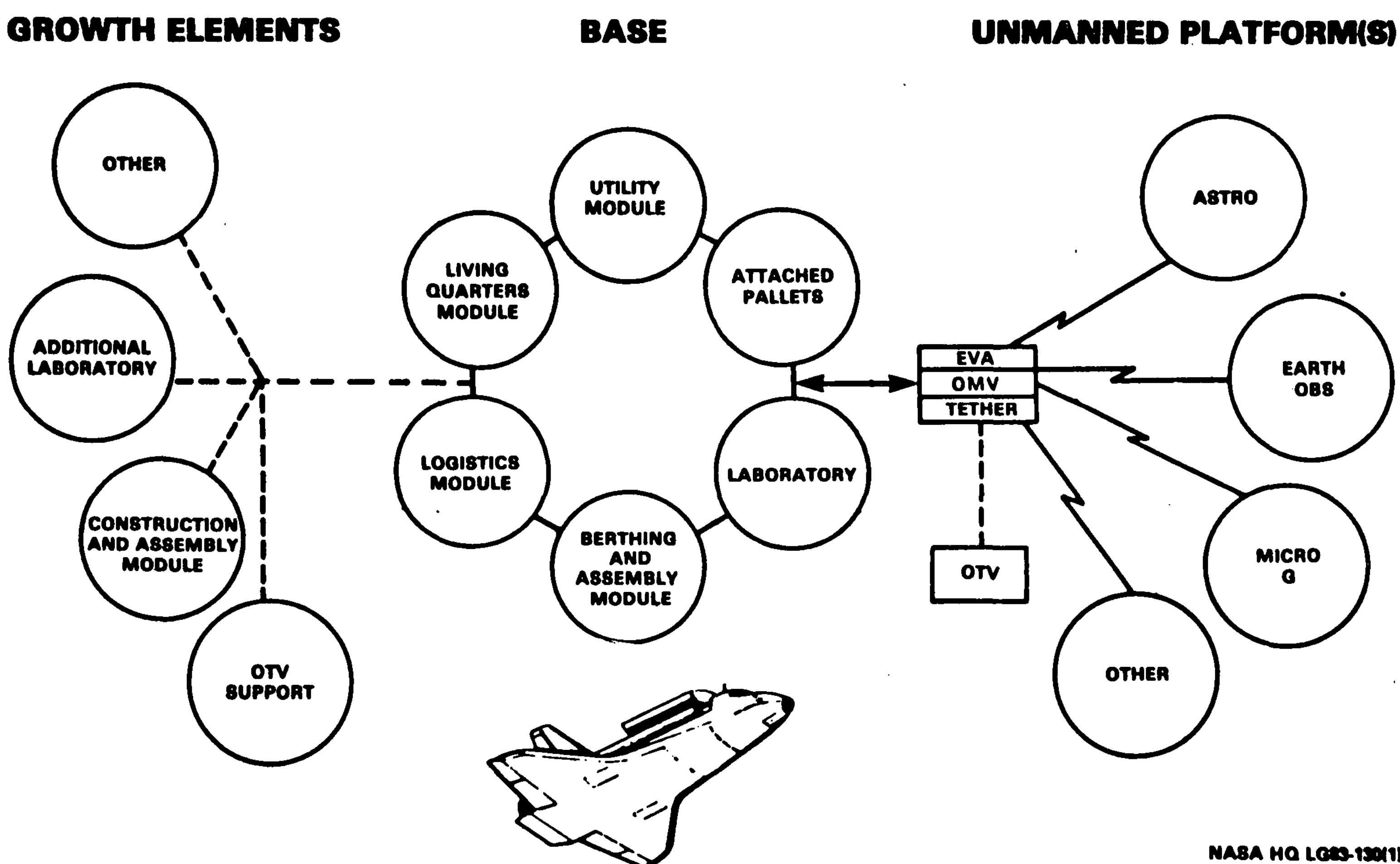
5.2 CANDIDATE SPACE STATION SYSTEM ARCHITECTURE

The Space Station system is perceived as a combination of manned and unmanned facilities located in low Earth orbit (LEO) and interconnected by an orbital maneuvering vehicle (OMV) (See Figure 5-1). The Space Shuttle provides the logistics and transportation link with the ground, while an orbital transfer vehicle (OTV) provides access from the Space Station to a wide range of orbital inclinations in LEO and geostationary orbit and beyond to the planets and asteroids.

The manned facility - the Space Station - is a modular system that will begin modestly and grow in capability as well as physically to satisfy the program requirements as they evolve with time. The Space Station is both a node in the Space Transportation System (STS) and a staging base for activities in and beyond LEO. The Space Station will provide for onboard research and commercial activities requiring (or tolerant of) man's presence, assembly and construction of systems too large for the Shuttle cargo bay, and operational support to companion free-flying satellites and platforms. This operational support includes deployment, retrieval, and maintenance of satellites and platforms, changeout of experiments on the companion platforms, and staging of high-energy missions.

The unmanned facilities, satellites and platforms, will be operated in relative proximity to the Space Station in a manner that will allow periodic

FIGURE 5-1
SPACE STATION PROGRAM ARCHITECTURE: WHAT IS A SPACE STATION



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visits from the Space Station for maintenance, replenishment of consumables, and experiment changeout. The platforms provide power, communications, attitude control, and other services for a series of somewhat independent payloads. The payloads resident on the platform can be exchanged on a predetermined schedule as part of a long-term science and applications program. These platforms can be oriented toward a single discipline or designed to support a multi-disciplinary grouping of payloads as the requirements dictate. The satellites support highly focused science and applications activities intended for long-term space missions. While payload changeout might not be appropriate for satellites, the Space Station will provide for maintenance, instrument alignment and calibration, replenishment of consumables, and related services. The currently-approved Space Telescope and the Gamma Ray Observatory will be launched before the Space Station and can be first elements of a space orbital operations system.

The OMV provides the operational link between the Space Station and the companion free flyers. The OMV will transport satellites and platforms from the Space Station to their operational destination and retrieve them as required. In-situ servicing and payload changeout will be provided by the teleoperated capability of the system. An OMV is currently being defined for operation out of the Shuttle cargo bay. The propulsive capability of the Space Station based OMV will be driven by the location of the satellites and platforms relative to the Space Station. The OTV provides access from the Space Station to a wide range of orbital inclinations in LEO, to geostationary orbit, and beyond to the planets and asteroids. This service is presently being provided by expendable launch vehicles and the Shuttle. The Space Station can also provide for the mating and checkout of payloads enroute to geostationary orbit where the payload and upper stage cannot be accommodated together in the Shuttle cargo bay. The Space Station would be designed to maintain, refuel, checkout, launch, and recapture this reusable, space-based OTV.

This proposed architecture has other distinct advantages. The platform clusters can be designed to communicate only with the Space Station, wherein the Station could perform data processing and data compaction for retransmittal to Earth. Since the distance between the clusters and the Space Station would be small, the communications systems design is rather simple. A Space Station, tending a cluster of unmanned platforms, permits consideration of power system designs based on the replenishment of expendables such as fuel cells for the unmanned platforms. A man-tended, Earth observation platform that would contain a synthetic aperture radar would enable the retrieval of a holographic tape from the platform, rather than demand the transmission of the information to Earth via a wide-band data link. A man-tended, astronomical platform would enable the replenishment of cryogens and the ability to readily change focal plane instruments.

The high degree of adaptability of this architecture is not the only advantage of this concept. The major benefit derived from this concept is that competing and conflicting demands for the Space Station Program are isolated and need not invoke serious systems compromises nor create a major technological hurdle to resolve competing demands. This architecture is also applicable across all orbital inclinations in low Earth orbit. An initial Space Station complex could be placed in a low inclination (28°-57°) orbit to service science, commercial, and geostationary missions. A second station complex could later be placed in near polar orbit (70°-98°) to service Earth observation and other missions.

The major elements that must be developed to fulfill the proposed architecture shown in Figure 5-1, are as follows:

- A manned Space Station designed to support onboard research and development activities as well as operational activities (e.g., satellite and platform servicing, assembly and constructions, basing for a reusable OTV, payload checkout and calibration, etc.);
- Unmanned satellites and platforms for missions requiring an unmanned environment (e.g., accurate pointing, long-term stability, minimum contamination, etc.);
- An OMV to provide access from the Space Station to the companion satellites and platforms; and
- An OTV for access to geosynchronous altitude and for conducting high-energy escape missions.

5.3 SPACE STATION DESIGN CONSIDERATIONS

Once the architecture of the overall space operations system is determined, the design of the Space Station itself can be initiated. Although significant definition exists for several Space Station configurations, it is premature to focus on any one specific approach at this time. Rather, the maturing definition process that emphasizes a knowledge of current and projected user requirements, the utilization of efficient advanced technologies, and the need for a cost-effective evolutionary capability will lend the necessary insights.

The process of developing a Space Station configuration requires a consideration of some fundamental parameters, several of which are discussed below.

5.3.1 Flight Characteristics

Altitude, inclination, and orientation provide a set of interactive, complex, system design variables. The Space Station configuration architecture is influenced by solar attitude to accommodate solar power systems, heat rejection, and, potentially, some viewing constraints. The orientation must attempt to minimize or maintain acceptable drag profiles for control and orbital decay/ makeup purposes. The orbital altitude operating range affects control disturbance torques, orbit decay rates, and rendezvous capability (cost-effective STS performance to orbit). Several solutions exist to this set of variables, but continuing definition and analysis in conjunction with the potential design options and mission requirements are essential to a full understanding and resolution of approaches.

5.3.2 Evolution Strategy

There are several evolutionary or growth modes available for the Space Station. The Space Station could pursue a replacement approach (i.e., block I followed by block II), an evolutionary growth by addition of modules (i.e., habitat module, resources module, etc.), or growth through replication of the basic Space Station to accommodate different or additional missions. Growth through subsystem updates is expected to be inherent in any of these options and the final growth mode(s) selected is likely to involve a combination of the basic options.

The replacement approach could consist of deployment of a near-term, low-cost Space Station with growth capability. This early step would be utilized to comprehensively conduct near-term missions and would provide a substantial degree of learning for later expanded missions. After proceeding through early mission support and advanced capability development on the early Space Station, a block II Space Station could be launched to accommodate the more difficult or advanced missions.

Growth by evolution could start with a modest Space Station, and, as the mission requirements grow, additional modules could be added. For example, as the need for power grows, an additional module could be added to the Space Station to provide this resource. Or, if additional crew members are required to support the missions, an additional habitat module could be attached.

Additional growth capability inherent in most basic concepts is to design the initial Space Station to accommodate anticipated subsystem improvements. If additional power is needed, the solar array could be replaced with a larger or improved one, or blanket sections could be added to the existing array. Another example is to initially design the data or information management system to accommodate additional capacity or hardware types with minimum impact to the Space Station. These examples reflect means to incorporate evolving technology, and they also place considerable emphasis on interface standardization to facilitate implementation.

5.3.3 Time-Phased Capability

The time-phased capability for accommodating science and operations-type mission needs is one of the obvious major variables, and the extent of impact to heavily support either science or operations is implied throughout the concepts under consideration. Based on recent studies and preliminary mission requirements, the initial Space Station should be designed to support a reasonable mixture of science and operations capabilities onboard, although the mixture is a subject of further analysis. In addition, the Space Station should be designed to support a limited set of activities during the initial year but incorporate provisions for easy on-orbit growth for evolving mission needs.

The Space Station is envisioned as a system that provides an incremental or phased development and buildup in a manner that fulfills the time-phased mission requirements. Modularity and commonality are seen as some of the means to help accomplish this growth flexibility within the budgetary constraints. In addition, Space Station functional activities will grow more complex through the years, which creates significant influences on the congregation or dispersal of functions.

Planning the internal system architecture begins with the congregation of various prospective functions into modules. From past experience with Skylab and many NASA Space Station studies, much has been learned about the separate versus complementary nature of different functions. In particular, functions such as basic resources, habitation, and logistics are best modularized into separate entities. However, there still exist numerous approaches for separating the entities into distinct Space Station modules. For example, a safe-haven capability could be accommodated in a dedicated module through dual habitability modules or by integrating this capability in an existing module. Other functional distribution options include: (1) Separation of the Space Station control functions in other modules, such as the habitat module; and (2) incorporating some functions (e.g., waste management, extra crew accommodations, or a payload section) in the logistics module versus including this capability elsewhere.

Commonality of hardware is desired to assure compatibility and minimize program development and life cycle costs. Commonality goals would be applicable to modules, submodules, subsystems (including structural, electrical, and fluids), and software. Several potential areas of commonality include: (1) Use of common structural building blocks including module design and diameter throughout the Space Station; (2) applicability of Space Station modules, subsystems, and software on unmanned platforms; (3) Space Station design for operation at multiple orbits (e.g., 28.5°, 57°, polar, or GEO) as compared to design for operation at single orbits; (4) applicability of Space Station hardware and software for a manned GEO capsule; (5) multi-purpose versus dedicated payload support facilities and services; and (6) the benefits of commonality to Space Station maintenance. A primary effort in the definition phase will be to address the feasibility of common hardware and software usage throughout the space operations system. Key parameters to be considered are payload accommodations, system design, development and testing implications, weight, logistics, and costs. System interface standardization is another inherent area of interest/benefit in commonality as well as evolution.

5.3.4 Launch And Orbital Assembly Capability

Another configuration architecture variable that must be well understood is Earth-to-orbit transportation and its effects, impacts, and benefits on the total system. The reference transportation mode is the Space Shuttle with its known capabilities. There is, however, the potential of an aft cargo compartment behind the external tank, which, if developed, could possibly offer modules with diameters of over 20 feet. These modules, although they could not be returned in the cargo bay, may offer an attractive design latitude. Also, there is planning toward other STS derivatives that could offer increased capability in launch mass and potentially lower transportation costs. Although not required at this time, it is important to understand the benefits and implications for these kinds of capability increases.

Other major variations involve the potential utilization of the Shuttle external tanks, the use of deployable tether systems in the basic Space Station geometry, and the potential of a separate formation flying station dedicated to the generation of propellants and energy-producing fluids. The external tank concepts have potentially attractive uses such as hangars or construction support structures. Tether systems are being investigated and potentially offer a facility for selected mission accommodations such a placing selected station elements in a small (less than 0.1 g) field, while others remain at reduced gravity. The separate station for generating energy-producing fluids would potentially allow a basic Space Station without large solar arrays and thus significantly affect general architecture and orientation considerations. All these possibilities will be considered in the final analysis of requirements, capabilities, and program structure.

5.3.5 Program Resources

Finally, the program resources establish a rather important constraint in that the configuration architecture provisions in size and capability must not exceed established program costing plans. For this reason, the final design must recognize development and life cycle costs while spanning a degree of capability that readily matches can be found for approach and resources.

5.4 KEY SUBSYSTEM CHARACTERISTICS

The Space Station as an entity is made up of a set of subsystems. The final definition of the Space Station subsystems and the system topography that integrates them will result from a top-down systems design responsible to the Space Station functional requirements and system definition. Criteria for deriving subsystem definitions and a system architecture should include: (1) Defining stand-alone subsystems with simple verifiable interfaces; (2) separating functions to permit evolution and change without affecting other functions; and (3) separation of critical from noncritical functions. Indications are that subsystems should be highly autonomous, maintainable and verifiable on orbit, compatible with a phased Space Station buildup, and capable of growth and changes as mission needs evolve. This approach will inherently cause the subsystems to incorporate data handling and processing into their design. To minimize system integration problems and costs, a high degree of interface standardization will be imposed on all automated subsystems. This is especially important with respect to general purpose processors, operation system software, and data/communications. Hardware/software commonality will be an important goal for minimizing development and life cycle costs.

Table 5-1 lists the key subsystems, their functions, and associated design considerations.

TABLE 5-1
SPACE STATION SUBSYSTEMS, FUNCTIONS, AND DESIGN CONFIGURATIONS

Subsystem/Function	Design Considerations
(1) Onboard Data Management	
- Data Storage - Data Computation - Data Distribution/Control	- Degree of Decentralization - Extent of Automation - Interface Options - Equipment Technology Options - Redundancy/Degree of Fault Tolerance - Overall Data System Architecture
(2) Environmental Control/Life Support	
- Atmosphere Control/Revitalization - Water System Control - Cabin Pressure Control - Consumables Storage/Regeneration	- Degree of O_2 Recovery - Degree of H_2O Recovery - Technology/Equipment Options
(3) Structures, Mechanisms, and Materials	
- Module/Element Basic Support Structure - Interface Structures - Mechanisms - Materials	- Module Diameter and Wall Construction - Material Selections - Metallics or Composites - Mechanism Techniques - Special Structure Options
(4) Crew Systems/Habitability	
- Basic Habitability	- General Accommodation Volumes and Zones
- Crew Equipment/Provisions - Food Preparation/Provisions - Personal Hygiene	- Effective Equipment Options
(5) Extravehicular and Intravehicular Activities (EVA/IVA)	
- EVA/IVA Subsystems - EVA/IVA Equipment - EVA/IVA Procedures	- Pressure Level Options - Suit Options - General Provision Options
(6) Electric Power	
- Power Generation	- Solar, Fuel Cell, and Nuclear Options
- Energy Storage - Processing and Conditioning - Power Distribution	- Power/Voltage Levels - Energy Storage Options - AC Versus DC Distribution

TABLE 5-1
SPACE STATION SUBSYSTEMS, FUNCTIONS, AND DESIGN CONFIGURATIONS
(Continued)

Subsystem/Function	Design Considerations
(7) Thermal Control	
- Heat Acquisition/Control	- Centralized or Decentralized
- Heat Transmission	- Single-Phase Versus Two-Phase Heat Transfer
- Heat Rejection	- Type Radiators
(8) Fluid Storage and Handling	
- Centralized Fluid Storage	- Degree of Centralization/ Commonality
- Fluid Distribution/Management	- Storage Options - Resupply Options
(9) Guidance, Navigation, Stabilization, and Control	
- Position Control	- Integration of Guidance and Navigation with Stabilization and Control
- Attitude/Orientation Control	- Control Law and Technique Option - Orientation/Arrangement Variables
(10) Communications and Tracking	
- Transmit/Receive Data, Voice, TV	- Onboard Space Station Capability Options
- Relative Tracking of Orbit Elements	- Extent of Interaction/ Support With Other Elements
(11) Health Maintenance	
- Crew Health Maintenance	- Provisions for Health Maintenance - Crew Safety
(12) Controls and Displays	
- Crew Controls	- Type and Extent of Consoles
- Crew Displays	- Effective Crew Interaction
(13) Airborne and Ground Support Functions	
- Data Management - Space Station Operations Center - Payload Control	- Existing Equipment Use - Minimization of Equipment - Commonality - Location and Flow of Functions and Supporting Facilities

6.0 SYSTEMS OPERATIONS

6.1 INTRODUCTION

In order to develop operational philosophies and requirements for a Space Station Program, an Operations Working Group (OWG) was formed in July, 1982. The Group was chaired by the Kennedy Space Center and composed of and supported by personnel from all of the NASA Centers.

The OWG sought guidance, information, and support from the Space Station Task Force (SSTF), the Concept Development Group, the Mission Requirements Working Group, and the mission analysis studies and operational studies conducted by various contractors, NASA Centers, and others in order to accomplish these tasks. From these sources and through the OWG's own efforts, the Space Station operational approaches, scenarios, groundrules, philosophies, and requirements were formulated. The OWG's own efforts included the conduct of major trade studies for the operational disciplines of: (1) Maintainability, (2) automation, (3) operations philosophy, (4) customer interfaces, (5) safety, and (6) prelaunch processing. These were further sub-divided into various tasks and resulted in the performance of 42 different trade studies. These efforts enabled the development of Book 6 and the "Space Station System Operational Requirements" document. A brief description of the operational philosophies and a synopsis of the operational requirements follow.

6.2 OPERATIONAL PHILOSOPHIES

The top level operational philosophies under which all the operational trade studies were performed and the requirements developed included the following considerations:

(1) Programmatic Considerations: The Space Station Program should have an operations organization function equal to other functions. Early participation by operations personnel in the Space Station concept development, definition, and design and an early operations budget should be established to foster adequate planning. Operational requirements should be established early for the program and

published in appropriate documentation. Other system and mission requirements should be compatible with those developed for operations.

(2) Maintainability/Maintenance Considerations: A program maintenance organization should be established and a program maintenance budget allocated for the purpose of developing and specifying the maintainability/maintenance requirements for hardware and software. The program elements should be conceived, designed, and built to be serviced and maintained on-orbit and on the ground, and provisions should be made to isolate problems and easily replace and/or repair hardware and software.

(3) Automation/Autonomy Considerations: The capability should be developed to achieve low-cost, easily maintainable and progressive/evolutionary automation of systems and subsystems to achieve autonomy from the ground as well as on-board machine autonomy from the crew. Operations should also allow for the use of the flight crew for the performance of tasks where crew members capability and utility provide for an operational and cost-effective alternative to automation/autonomy.

(4) Customer Interface Considerations: A customer advocacy function should be established to assure that customers are provided with simple, easily understood, stable, and well documented interfaces and requirements.

(5) Ground Control and Support Considerations: Advanced planning should allow for ground control and support of the program elements during initial buildup. As the program matures, control and support functions from the ground to the on-orbit elements should occur. Separate (autonomous) payload operations control centers (POCCS) should be provided by the customer.

(6) Prelaunch Operations Considerations: An early recognition of the complexity of initial prelaunch operations is essential in order to provide for adequate planning for these operations. In addition, a long term verification program will be needed to support an evolving growth capability on-orbit.

6.3 OPERATIONAL REQUIREMENTS

The requirements summarized herein apply only to the Space Station Program Elements. They do not apply to operations and design of privately-owned and operated flight elements and payloads, except for those requirements that deal with safety or interface compatibility. The safety and interface compatibility requirements apply to all customers using the Space Station Program and need be developed to minimize cost to the users.

6.3.1 Overall Operations

Overall operations are divided into four subcategories: (1) prelaunch processing and launch operations; (2) on-orbit flight operations; (3) ground support operations; and (4) logistics operations.

6.3.1.1 Prelaunch Processing and Launch Operations

The ground operations necessary to support integration and checkout during both the initial establishment of an on-orbit system and the subsequent operational era include element and interface verification, interaction with the Space Transportation System (STS) and ground systems, element refurbishment and reflight, servicing/deservicing of all elements, payload ground operations, ground support of on-orbit operations, abort/contingency planning operations, and on-earth transportation of elements to the launch site. To assure that the integrated flight and ground systems satisfy the applicable requirements is the primary objective of the ground operation verification process. The result of each complete prelaunch ground operations process shall be a launch-ready assembly of components, subsystems, and system elements of the desired configuration with all related interfaces compatible and functional.

Following the initial establishment of an on-orbit system, the interface verification will present a unique operational challenge, for the system will be on-orbit before some elements and payloads are built; hence, there is no possibility of a physical interface ground integration test. A method for verifying new interfaces and procedures shall be developed to ensure proper operation with all elements, systems, and payloads on-orbit and to demonstrate end-to-end system operability and maintainability before committing them to launch. In addition, a verification program shall be provided to assure that all modifications and upgrades function properly.

Ground support equipment (GSE) and facilities shall be provided to support the prelaunch element handling, assembly, and checkout activities.

6.3.1.2 On-Orbit Flight Operations

The Space Station Program will consist of both manned and unmanned elements delivered to orbit by the STS. Initial assembly, activation, and checkout shall be accomplished using the STS and STS delivered crew members. Following these activities, the Space Station shall be manned at all times unless unforeseen circumstances force the crew to retreat to a safe haven or evacuate the Space Station, in which case the Space Station shall be designed for limited operation in an unmanned mode. The STS shall continue to perform resupply/crew rotation functions throughout the Space Station life. Ground support functions shall be required during the initial assembly, activation, and checkout, but autonomy from the ground shall be implemented as the Space Station matures and becomes operational.

The Space Station elements and systems and crew size shall be capable of evolutionary growth. A variety of missions shall be performed by the crew, including proximity operations, EVA operations (using manned maneuvering units), operation and servicing of internally and externally attached experiments, payloads, and laboratories, servicing of free flyers, Orbital Maneuvering Vehicle (OMV) operations, servicing of platform-mounted experiments/payloads, and eventually, test and deployment of upper stages, operation of Orbital Transfer Vehicles (OTV), and large scale construction/assembly of payloads.

The Space Station shall provide non-mission unique basic services to customers. Customers shall arrange for mission unique services.

The Space Station shall be operated on a 7 day week, 24 hour day basis with the crew time allocated as a resource. The crew shall have the training for and capability to perform activity planning. On-board aids, computer terminals, and accessible and modifiable software shall be available to the crew to assist them with maintenance procedures and training, as well as provide them with system and subsystem documentation. In addition, a functional operational database and configuration management system shall be maintained on-board the Space Station for the crew as well as on the ground.

An on-board information management system shall provide, as a minimum, system maintenance and troubleshooting procedures, consumable status, and repair and replace information. System/subsystem validation shall be performed with a minimum of crew interaction and shall be able to be initiated automatically or manually.

Design of the Space Station shall be such that standardized procedures can be used for many types of system activity.

Subsystem reconfiguration in case of failure shall be capable of being performed automatically or with crew assistance.

Voice contact with the mission support team shall be provided. Space Station health and status data and payload data downlink to the mission ground support system shall be provided. The Tracking Data Relay Satellite System (TDRSS) shall be used for communications.

6.3.1.3 Ground Control and Support Operational Requirements

Ground functions shall support the operations of STS, Space Station, space platforms, payload control, and OMV, and OTV. The ground support system shall monitor STS activities during launch, landing, rendezvous, and major system failures, and shall provide support for the initial buildup and activation phase of the Space Station.

Ground support shall be limited to contingency operations, backup trajectory services, and payload support during the operational period after initial buildup.

Separate autonomous operations for payload ground support shall be provided by the customer.

Long term activity planning shall be accomplished on the ground as well as the majority of crew and customer training. However, some crew training shall be accomplished on-board the Space Station. Training shall be as specialized as possible, but adequate cross-training shall be provided to allow for backup operation of critical systems and to allow for the performance of critical tasks by all crew members. Ground control/support personnel shall also receive proper training for support.

6.3.1.4 Logistics Operational Requirements

An integrated logistics system encompassing maintenance, provisioning, supply support, support equipment, training packaging/handling, transportation, facilities, and technical data/publication shall be established and maintained to support flight and ground operations. Logistics considerations shall be an integral part of all program phases.

6.3.2 Safety Requirements

Ground rules and constraints for safe Space Station system operations shall be established to provide for redundant habitats and rescue capability for the crew, fail operational/fail safe and restorable levels of redundancy in safety critical systems, and minimum risk to systems from mission operations and design. Payloads shall meet the safety requirements for transport in the STS and operations in or attached to the Space Station.

6.3.3 Operational Medical Care Requirements

On-board medical care facilities, training, and equipment shall be provided that are appropriate to crew number, operational complexities, and the best assessments of potential for injury and illness. Environmental hygiene and general habitability concerns shall be provided in the Space Station design. Additionally, generalized prelaunch health screening for the flight crew shall be performed.

6.3.4 Customer Operational Requirements

To achieve maximum benefits from the Space Station, design and operations shall provide a high degree of customer interaction with the flight crew and the payloads, thus enhancing the effectiveness of the system for the customer. When required, the customer shall provide payload specialists for specific missions.

Space Station data systems for payloads shall be transparent, requiring minimum customer interaction for data reconstruction. Scientific and payload data shall be recovered with a minimum of ground processing. Payload Operating Control Centers (POCCs) shall command and monitor payloads independently, subject to safety and compatibility constraints.

The operational approach shall be planned to reduce requirements placed upon customers by minimizing the number and complexity of interfaces, and maximizing customer involvement. The Space Station shall provide the customer an affordable, dependable, available, friendly, and flexible service.

6.3.5 Automation Requirements

A high degree of Space Station autonomy from the ground shall be required. Subsystems shall be as functionally independent as practical to facilitate maintenance and automated to the fullest extent practical; however, the ground or flight crew shall be able to change automated sequences and limits in real time and on-line. The Space Station shall be progressively automated as procedures and designs evolve during the life of the Space Station.

Continuous subsystem monitoring by either the flight crew or the ground shall not be required for normal Space Station system operations; however, the crew shall be able to monitor all subsystem health and status data.

The flight system shall be used to the maximum to reduce requirements for Ground Support Equipment (GSE) and other support during ground testing to the flight systems.

A single high order test and control language shall be used to generate the application software for ground testing and operations as well as the on-board operations. This language shall be available to the customers as an option. This language for customer control and communication shall be user friendly and technically adequate to meet the requirements of all user disciplines and Space Station operations.

6.3.6 Maintainability/Maintenance Requirements for Hardware and Software

Reliability/maintainability shall be a prime consideration in design of the Space Station Program elements. A program level document specifying maintainability requirements for on-orbit and ground maintenance shall be developed.

Each element shall be instrumented for detection and isolation of failures to the orbital replacement unit (ORU) level. Equipment shall be designed for easy removal, repair, and replacement to the lowest level practical. Systems and subsystems should be designed so repair can be done by removal and replacement. The ORUs shall be independent of each other so that replacement of one shall not require removal, replacement, or disconnection of another. Critical systems shall be able to undergo maintenance without interruption of critical services and shall be "fail safe" during maintenance. Software shall be designed and developed to minimize maintenance costs.

The Space Station shall contain controlled storage facilities for storing test equipment and spares.

Equipment design and operations shall allow for the judicious use of Extravehicular Activity (EVA) for maintenance.

6.3.7 Commonality

Commonality and interchangeability of both hardware and software to the ORU level or equivalent shall be required where feasible for both flight and ground systems to simplify the logistics and maintenance activities, minimize costs, and reduce spares storage.

6.3.8 Habitability Requirements

Operational habitability requirements that deal with psychological and physiological well-being, health, and comfort are designed to maintain the morale and increase productivity of the crew members.

Attention shall be given to optimizing the crew number and mix and developing a proper command structure. Accommodations for the crew shall be comfortable and adequate for the tasks to be performed. A shirtsleeve environment shall be provided by the Environmental Control and Life Support System (ECLSS). Adequate lighting without artificial or sun glare shall be provided. This lighting shall be variable to suit the tasks and shall be controllable by the crew. Access and egress ports shall consider traffic patterns. Noise levels shall permit normal conversation.

There shall be separate areas for dining, lounging, meetings, sleeping, and food preparation. Bathing and toilet facilities, the galley, and sleeping quarters shall be located separate from each other. There shall be observation windows/ports for work-related and recreation tasks. Free time shall be available for each crew member each day and exercise devices shall be provided.

Person-to-person communications between the Space Station and the ground and within the Station shall be provided. Private two-way TV and voice communications with family members shall be provided. No censorship of communication between crew members and their families shall be imposed, except for national security reasons.

6.3.9 Operational Security Requirements

The Space Station command and data handling system shall be capable of secure communications as required for normal and emergency operating conditions. Secure voice/video communications shall also be provided between the flight crew and the ground. The command link shall use command authentication.

Secure provisions for hands-on and visual access to payloads shall be provided. Payloads requiring secure command and data handling shall be responsible for command and data encryption within the payload and on the ground.

6.3.10 Operational Quality Assurance

A program level document specifying quality assurance goals and requirements, disciplines, and controls shall be developed for equipment and software for implementation during ground and on-orbit operations. An effective system shall be implemented to validate the acceptability and conformance of hardware and software and their operations.

Prevention of defects and correction of problems to prevent recurrence shall be a prime consideration of the quality effort.

7.0 PROGRAM PLAN

7.1 INTRODUCTION

The Program Plan (Book 7) describes the overall management, technical, and procurement approaches for the Space Station Program. The current primary emphasis is on the definition and preliminary design phase and the definition of issues related to the program development and operation phases.

7.2 PROGRAM PHASES

The planning schedule for the Space Station Program is shown in Figure 7-1. The activities are geared toward an initial operational capability (IOC) in the early 1990's, and the necessary planning to support an evolutionary development process from the IOC to a growth capability in the year 2000.

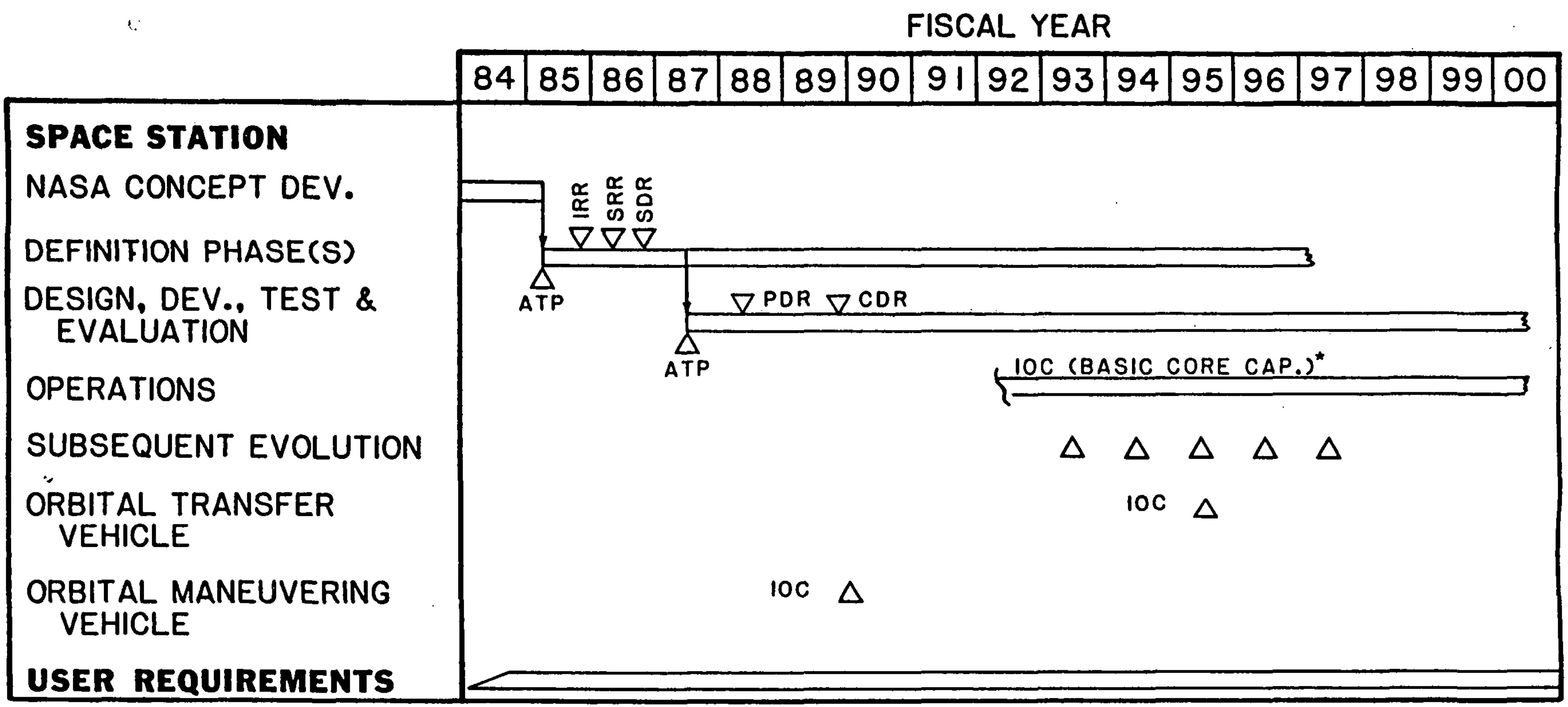
7.2.1 Definition Phase

The initial definition phase will be conducted in FY 85 thru FY 87. While the initial definition phase provides the preliminary design for the IOC, it will also provide definition for the design growth for the year 2000 capability. The definition phase includes system requirements and interfaces, supporting systems and trade studies, a preliminary system design, prototype hardware and software, test beds, and detailed plans for the development phase.

7.2.2 Development Phase

The development phase is planned for an FY 87 start. Development includes the design, manufacture, and test of hardware elements, and the integration, delivery, and assembly of elements on orbit to achieve the initial Space Station capability in the early 1990's. Development is planned to continue beyond IOC to support the growth capability.

FIGURE 7-1
SPACE STATION OVERALL SCHEDULE



ATP - AUTHORITY TO PROCEED
CDR - CRITICAL DESIGN REVIEW
IRR - INTERFACE REQUIREMENTS REVIEW
PDR - PRELIMINARY DESIGN REVIEW
SDR - SYSTEM DESIGN REVIEW
SRR - SYSTEM REQUIREMENTS REVIEW

△ - INCREASED CAPABILITY
* - ON-BOARD EXPERIMENTS, SERVICE, AND PLATFORMS

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7.3 PROGRAM OBJECTIVES AND GUIDELINES

The goals of the Space Station Program, as directed by President Reagan in his State of the Union Message on January 25, 1984, are for NASA to:

- Develop a permanently-manned Space Station and to do so within a decade;
- Invite other countries to participate; and
- Promote private sector investment in space.

In support of these goals, the following long-term, Space Station Program objectives have been established by NASA:

- Establish the means for permanent presence of people in space;
- Enable routine, continuous utilization of space for science, applications, technology development, commercial exploitation, national security, and operations;
- Develop and exploit the synergism of the man-machine combination in space;
- Provide essential system elements and operational practices for an integrated national space capability; and
- Reduce the cost and complexity of working and living in space.

To achieve these objectives, management and engineering related guidelines have been developed as shown in Table 7-1.

7.4 PROGRAM MANAGEMENT

The Space Station Program will be a national undertaking; one that will involve NASA, other U.S. government agencies and departments, private commercial customers, and international space agencies. Negotiation of the necessary agreements with these organizations will be a NASA Headquarters responsibility.

The program management approach will use the "Lead Center" approach with program offices established at NASA Headquarters and the Lead Center.

TABLE 7-1
SPACE STATION PLANNING GUIDELINES

MANAGEMENT RELATED

- Three year extensive definition (5-10% of program cost)
- NASA-wide participation
- Development funding in FY 1987
- IOC: early 1990's
- Cost of initial capability: $8.0B
- Extensive user involvement
  - Science and applications
  - Technology
  - Commercial
- International participation

ENGINEERING RELATED

- Continuously habitable
- Shuttle dependent
- Manned and unmanned elements
- Evolutionary
- Maintainable/restorable
- Operationally autonomous
- Customer friendly
- Technology transparent

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Project offices will be located at the various development Centers. Figure 7-2 shows a three-tiered management structure that is envisioned for the program (Levels A, B, and C). The responsibilities are described below.

7.4.1 Level A Space Station Program Office

The Level A Program Office will reside at Headquarters and be responsible for establishing program policy, budget and schedule guidelines, and for coordinating and interfacing with external organizations. This Office is also responsible for providing program direction and management, program requirements definition and control, utilization and operations planning, programmatic planning and implementation, and advanced development program coordination.

7.4.2 Level B: Program Management

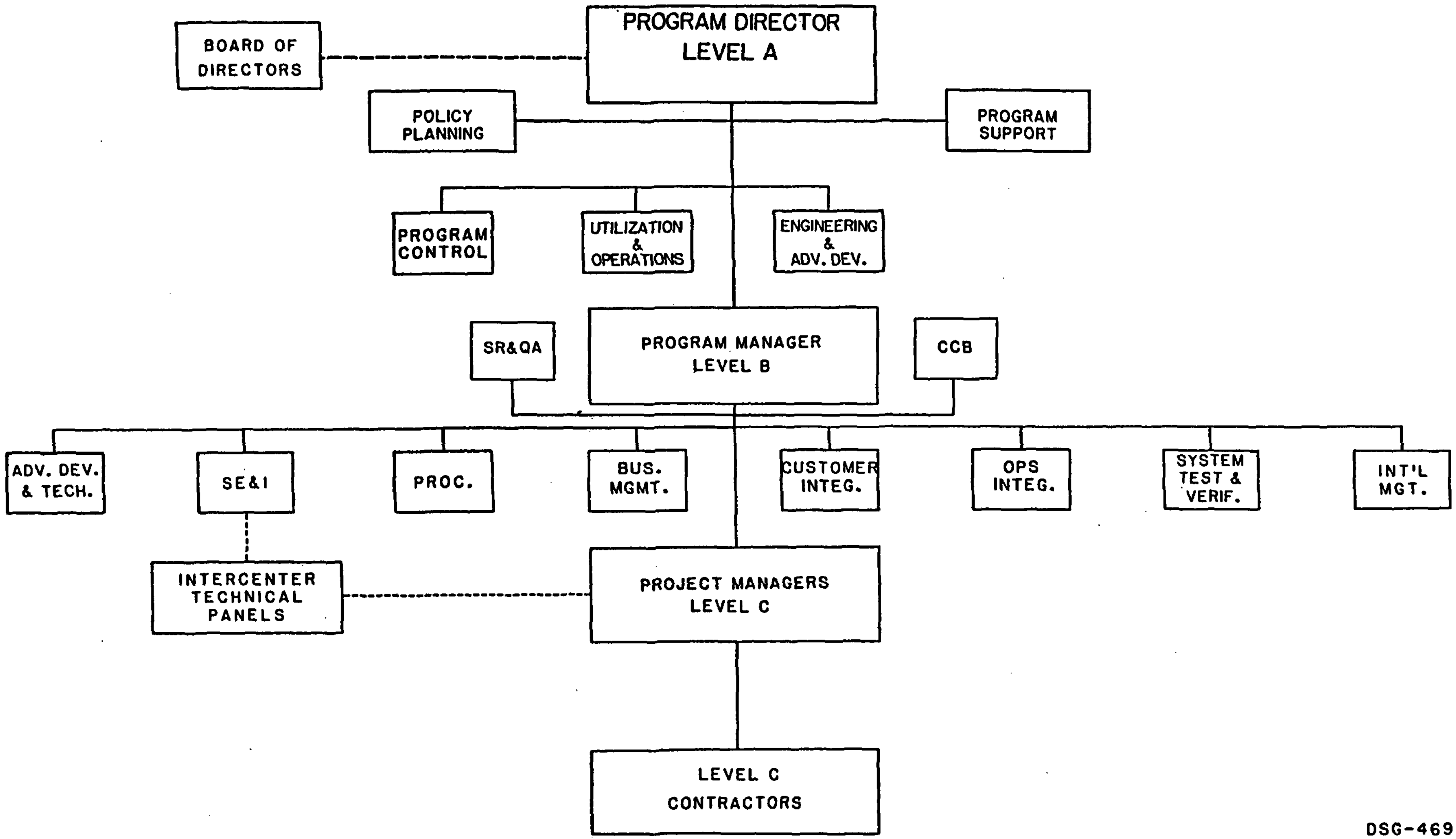
The Johnson Space Center has been selected as the Level B Program Management Center. This level is responsible for daily management of the Space Station Program. This includes:

- Systems Engineering and Integration: Establish and manage the technical content of the Space Station Program in response to the system requirements established by Level A.
- Business Management: Manage the program resources to the budget and schedule guidelines provided by Level A.
- Operations Integration: Assure that Space Station operations considerations are properly incorporated in the derivation of requirements and design of the system.
- Customer Integration: Manage the integration of customer requirements to assure customer needs are met.
- Support of Level A: Provide overall support to Level A during budget and schedule formulation, establishment of system requirements, and other aspects of program direction.

7.4.3 Level C: Project Management

Level C is responsible for the design, development, and verification of all hardware, business management of the projects, and management of all element design and development contractors.

FIGURE 7-2
PROGRAM/PROJECT MANAGEMENT LEVELS



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7.4.4 Advanced Development and Test Beds

NASA has established seven inter-center teams to conduct advanced development activities for potential use in Space Station design and development. The technology teams and center assignments are shown in Table 7-2. Level A will provide management coordination with the other Headquarters offices and establish overall guidelines and controls. Level B will be responsible for coordination of all program technology development and ensuring funds are directed to those areas most critical to Space Station development. Level B will also coordinate the use of all test beds.

7.5 TECHNICAL APPROACH

7.5.1 Utilization

Utilization is the term applied to the overall process of identifying Space Station customers, defining and refining their requirements and needs, and integrating both requirements and customers into the Space Station Program design, development and operations. In order to accomplish the goal of high utilization, the Space Station must be "customer friendly" in terms of cost and usability. Dealing with customers -- potential and committed -- and ensuring that they are a major force within the Program is a primary consideration in the Space Station Program.

7.5.2 Operations

Emphasis must be placed on the new factors that arise in operating a permanently manned orbital facility in a cost-effective manner by using a customer-oriented operational approach to achieve maximum benefits. The Space Station will be managed to divide operating between the flight portion of the system and the ground in such a way that the capabilities of each are most effectively utilized. System autonomy will minimize ground control of the Station and on-board machine autonomy will minimize crew involvement in system monitoring; thus allowing the crew to maximize high return activities in

TABLE 7-2
TECHNOLOGY TEAMS AND CENTER ASSIGNMENTS

TEAM	LEAD	MEMBERS	SUPPORT
ATTITUDE CONTROL AND STABILIZATION SYSTEM	MSFC	JPL, JSC	LaRC
DATA MANAGEMENT SYSTEM	JSC	GSFC, MSFC, KSC	ARC, NSTL, JPL, LaRC
AUXILIARY PROPULSION SYSTEM	MSFC	LeRC, JPL, JSC	
ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM	JSC	ARC	
SPACE OPERATIONS MECHANISMS	MSFC	JPL, JSC, LeRC	LaRC
THERMAL MANAGEMENT SYSTEM	JSC	GSFC, LeRC, MSFC	
ELECTRIC POWER SYSTEM	TBD	JSC, LeRC, MSFC	JPL

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support of customer missions. The Space Station will provide non-mission-unique services such as data processing and communications.

7.5.3 Systems Engineering and Integration (SE&I)

The systems engineering and integration efforts consist of tasks required for defining and analyzing requirements, configurations, and interfaces, planning and developing integrated tests, and controlling interfaces and changes in the program. The Level B Program Office at Johnson Space Center will be responsible for establishing and implementing SE&I capability. NASA will perform this function in-house utilizing the expertise of other Centers where available.

7.5.4 Hardware Commonality

The Space Station will incorporate hardware commonality to the maximum possible extent to minimize cost and simplify integration, maintenance, and spare requirements, to provide compatibility among all elements to assure continued supply throughout the Space Station life, and to enhance system evolution.

7.5.5 Advanced Development

The Advanced Development Program is planned to support the Agency's goals for implementing and operating a Space Station system. The program serves as the umbrella for all technology development activities starting with the focusing of generic technologies to the Space Station application, development of prototype technology components and subsystems, their integration and testing in discipline test beds, and flight experiments and demonstrations as required.

7.5.6 Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA)

The Space Station Program offers an opportunity to reduce "the cost of doing business in space" without compromising safety or reliability. Trade studies will be conducted to identify and assess the areas of potential cost reduction. Tailored programs will be implemented for SRM&QA. Special analysis and emphasis will be given to corrective actions for failures during test and hazards identification and control measures.

7.6 PROCUREMENT APPROACH

NASA will procure Space Station hardware in a manner designed to accomplish the Agency goals. The acquisition strategy is keyed to the concepts of NASA performing in-house systems engineering and integration tasks previously conducted by contractors and concentrating contractor participation at the work package and element level instead of the total system level. Also, in recognition that the Space Station will be developed incrementally and constrained by the availability of budget authority, the Program will be based on design to cost.

7.6.1 Definition Phase

The initial procurement is for the conceptual definition of the total capability and the detailed definition and preliminary design of the initial operational capability of the Space Station. A single RFP will be released from which selections will be made for all work package contracts. Two or more fixed-price definition contracts will be awarded for each work package. Contractors may propose on one or more of the work packages. Proposals will be evaluated by a Source Evaluation Board (SEB) in accordance with applicable regulations. The Administrator will be the Source Selection Official.

After source selection and negotiations, it is planned to assign responsibility for the contract management to the Center that has the assigned work package responsibility.

The definition contracts, lasting 18 months, will define system requirements, develop supporting technologies and technology-development plans through ground, test bed, and flight experiments, perform supporting systems and trade studies, develop a preliminary design, define system interfaces, and develop plans and cost estimates and schedules for the succeeding design and development phase. By penetrating the design to the element level and demonstrating subsystem technology, NASA will be able to base program development decisions and development contractor selection on a greater understanding of program and technical risks.

7.6.2 Development Phase

Competition for the next phase (e.g., design, development, test, manufacturing, of flight systems) will be limited to the definition phase contractors unless it is in the best interest of the Government to alter this approach. New procurement documentation and new SEB's will be established for the development phase. While evaluation criteria will be developed by these new SEB's, it is anticipated that the contractors' products and performance during definition will be considered in the evaluation process. The design and development contractor selections will be made by the Administrator.

TM-86652

NASA

National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 2

MISSION DESCRIPTION DOCUMENT

Prepared By The:
SPACE STATION TASK FORCE

MARCH 1984

FINAL EDITION

National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 2

MISSION DESCRIPTION DOCUMENT

Approved By:

JOHN D. HODGE
Director
Space Station Task Force

PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
BOOK 6	SYSTEM OPERATIONS
BOOK 7	PROGRAM PLAN

SPACE STATION
MISSION DESCRIPTION DOCUMENT (MDD)
BOOK 2

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SPACE STATION
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BOOK 2

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1.0 INTRODUCTION AND SUMMARY

1.1 BACKGROUND

Over the past few years, NASA has been studying the question of the next logical evolution in space technology beyond that represented by the Space Shuttle. In the course of these studies, the potential applicability of manned systems to the effective accommodations of a wide range of perceived mission needs has emerged as a major theme. As a result, a Space Station Task Force consisting of personnel from NASA Headquarters and Field Centers has been formed to develop the mission and system requirements, system definition, and program planning for a Space Station system. The mission requirements activity will identify, collect, and analyze all space missions anticipated for the 1990s that require or materially benefit from a Space Station system. These missions will serve as the basis for defining the main elements of system architecture and the time phasing of system elements deployment. A Mission Requirements Working Group (MRWG), as shown in Table 1-1, was formed to integrate and analyze these requirements.

1.2 OBJECTIVES

The objectives of this Mission Description Document (MDD) are: (1) to identify and describe the mission opportunities that would be available to the broad user community with a Space Station system; and (2) to define the time-phased requirements of these missions on the Space Station concepts. This array of mission requirements will be incorporated into the overall Space Station Task Force effort to assure that the system functional requirements developed are consistent with the research, development, and operational needs of the broad community served by the system. The result of these efforts will be the creation of a national facility; a logical and necessary next step in the achievement of this Nation's space policy.

TABLE 1-1

MEMBERS
MISSION REQUIREMENTS WORKING GROUP

NAME	ADDRESS	FTS #
BRIAN PRITCHARD, CHAIRMAN	LANGLEY RESEARCH CENTER CODE 107 HAMPTON, VA 23605	928-4738
JOHN COLE	NASA HEADQUARTERS CODE MFR-13 WASHINGTON, DC 20546	755-3793
JIM DUNNE	JET PROPULSION LABORATORY MAIL CODE 180-701 4800 OAK GROVE DRIVE PASADENA, CA 91103	792-6904
CHARLES ELDRED	LANGLEY RESEARCH CENTER MAIL CODE 365 LANGLEY STATION HAMPTON, VA 23665	928-3911
DON GERKE	JOHNSON SPACE CENTER MAIL CODE KA-2 HOUSTON, TX 77058	525-2491
SOL GORLAND	LEWIS RESEARCH CENTER MAIL CODE 501-8 2100 BROOKPARK ROAD CLEVELAND, OH 44135	294-5159
STEVE HOLT	NASA HEADQUARTERS CODE MFA-13 WASHINGTON, DC 20546	755-8490 344-7579 (GSFC)
SI MANSON	NASA HEADQUARTERS MAIL CODE RSS-5 WASHINGTON, DC 20546	755-2413
PETE PRIEST	MARSHALL SPACE FLIGHT CENTER MAIL CODE PM01 MSFC, AL 35812 MARSHALL SPACE FLIGHT CENTER, AL 35812	872-5313

1.3 APPROACH TO DEVELOPING USER MISSIONS

The history of the utilization of near-Earth space for science, applications, commercial, and national security research and development programs is a rich one and provides a reliable guide to desirable near-future activities. User communities are large and mature and their research and development needs are identifiable in a relatively straightforward manner. The approach taken by the Mission Requirements Working Group, therefore, has been to access these communities through their representative offices at NASA Headquarters, in-place scientific, applications, and commercial advisory panels, and the appropriate established commands within the Department of Defense. These same sources, combined with previous NASA and industry studies, provided the principal repositories of user community knowledge for the eight contractors who conducted Mission Analysis Studies (see Section 2.1.2). Those findings represent a major element of the results reported in this document.

The sources of mission requirements were categorized into four major groupings: (1) Science and Applications; (2) Commercial; (3) Technology Development; and (4) National Security. Panels were organized for the appropriate mission groupings. These panels then accessed the relevant program offices, advisory panels, and field center experts to obtain the mission requirements. This effort was then integrated with the results of the Mission Analysis Studies and several foreign national and international agency studies to generate the full array of mission requirements reported in this document.

The final step of identifying the time phasing of these requirements will involve a judgmental blending of user need and estimated technology readiness, requiring an iterative interaction with other elements of the Space Station Task Force. This process began in May, 1983 in parallel workshops held at Langley Research Center (mission requirements) and NASA Headquarters (concept development). The results reported in this document represent the current results of the mission requirements activity and the Langley Workshop.

1.4 CATEGORIZATION OF USER MISSIONS

The Science and Applications, Commercial, Technology Development, and National Security mission panels, augmented by the eight Mission Analysis Studies contractors, have assembled an extensive list of potential missions/payloads that could be supported by a Space Station system. In this updated draft (June, 1983), potential National Security missions are omitted, but are expected to be included in later drafts. The data provided by the other three mission panels was sorted according to mission category, orbital location, payloads attached to the Space Station (pressurized and unpressurized), and payloads remote from but serviced/supported by the Space Station. The sorted data provided insight into the time-phased support requirements that will be imposed on a Space Station system and was used to define reasonable alternative Space Station program scenarios and the mission sets compatible with those scenarios.

1.5 SUMMARY OF OPERATIONAL CAPABILITIES

The mission requirements represent the desires of the users in the four mission categories discussed above without regard to the expected capabilities of the Space Station system. Most users would prefer to be accommodated in the initial Space Station system. Recognizing funding limitations, an evolutionary Space Station system is obvious.

The Space Station Task Force has created a Concept Development Group (CDG) to begin to develop a Space Station system architecture and program funding requirements. The CDG has prepared a strawman architecture for the initial and future Space Station system that are budget limited. These strawman architectures have been used to develop realistic time-phased mission models/requirements represented in this document.

The next two subsections will describe the potential Space Station mission roles and describe the time-phased operational capabilities of the Space Station system.

1.5.1 Potential Manned Space Station Mission Roles

The manned Space Station may have the capability to perform the following mission support functions:

(1) Pressurized laboratory;

(2) Base for attached payloads;

(3) Base for communications, command, and control (C^3) support;

(4) Base for deployment, assembly, and construction;

(5) Base for proximity operations;

(6) Base for remote maintenance, servicing, checkout, and retrieval;

(7) Base for payload integration and launch; and

(8) Base for preparing payloads for Earth return.

1.5.2 Space Station System Operational Capabilities

A preliminary estimate of the operational capabilities of the Space Station has been developed by the Concept Development Group. The initial Space Station will provide the following services to payloads:

(1) 57 kilowatts (kw) of continuous electric power;

(2) 120 cubic meters (m^3) of pressurized laboratory space divided into two 60 m^3 laboratories;

(3) Four or more articulated ports for attached payloads with utilities available at each port;

(4) A crew complement for payload operations of 5 to 7;

(5) A co-orbiting astrophysics platform with 12 kw of electric power; and

(6) A near polar (sun-synchronous) earth resources platform with 12 kw of electric power.

Following the initial operational capability (IOC), the Space Station will evolve to provide additional capability to users. The evolutionary development of the Space Station then proceeds with the following steps:

- 1991:
  - A space-based Teleoperator Maneuvering System (TMS) and satellite servicing facilities;
- 1993:
  - 4 to 6 additional crew members;
  - An additional 65 kw of electrical power to the payloads; and
  - Two additional 60 m^3 laboratory.
- 1994:
  - A space-based Orbital Transfer Vehicle (OTV) with its associated propellant storage tanks and hanger.
- 1996:
  - 4 to 6 additional crew members; and
- 2000:
  - The addition of a polar or sun-synchronous, manned Space Station with somewhat less capability than the initial Space Station but including a TMS.

1.6 CANDIDATE SPACE STATION MISSION SETS

The missions developed in Section 4 will be combined with the operational capability scenarios postulated in Section 5 to produce a time-phased set of missions. In the present draft, the "mission set" has been identified without quantitatively matching mission resource needs and the sizing of Space Station system capabilities. It therefore represents only a time-phasing and top-level categorization of mission requirements relative to the capability scenarios.

Future drafts of this document will complete the process of identifying time-phased mission sets, taking into account the Space Station resources and physical constraints.

1.7 SPACE STATION BENEFITS

The Space Station mission analysis activities consisting of the contract studies, the working group and panel activities, and the Space Station Mission Requirements Workshop have all contributed to a better understanding of potential Space Station benefits. Just as the Space Station supports a diverse set of mission activities, the benefits occur in a variety of ways. It does not appear that there is one benefit that clearly justifies a Space Station. However, the cumulative payoff of the benefits from various sources does create a compelling case for a Space Station. These potential benefits are summarized in four general categories.

(1) Mission enablement and enhancement. Long duration, low gravity, man-tended facilities enable life sciences research and materials processing development. Many missions are enhanced by man's active involvement and the ability to extend mission lifetime through servicing.

(2) Space commercialization. A Space Station research and development (R&D) facility and pilot plant facilities appear essential for the exploitation of the large potential related to commercial space materials processing.

(3) Higher productivity for space operations. Substantial cost savings for space transportation are possible by use of a Space Station to offload mission requirements from the Space Transportation System (STS), decrease STS on-orbit mission times, and increase effective STS load factors. Space-basing of OTV and TMS operations provide the highest productivity gains.

(4) Societal benefits. Tangible societal benefits result from mission impacts on knowledge and information, quality of life, and the national economy (particularly development of new commercial products). Intangible benefits can also be very important through the impact on national and international prestige resulting from U.S. leadership in space.

2.0 MISSION REQUIREMENTS APPROACH AND DATA BASE

To ensure that valid mission requirements are developed, it is necessary to utilize the broad base of prior mission studies and to explore new mission opportunities that exist because of a manned Space Station. A plan of attack was developed that should expose all potential Space Station missions. The purpose of this section is to describe the approach taken in defining mission requirements and to list the data sources for the study.

2.1 MISSION REQUIREMENTS APPROACH

The approach to defining user missions and their associated requirements was to establish NASA in-house working groups, fund mission analysis studies with the aerospace industry, and elicit parallel study efforts by other U.S. and foreign government organizations.

2.1.1 Mission Requirements Working Group

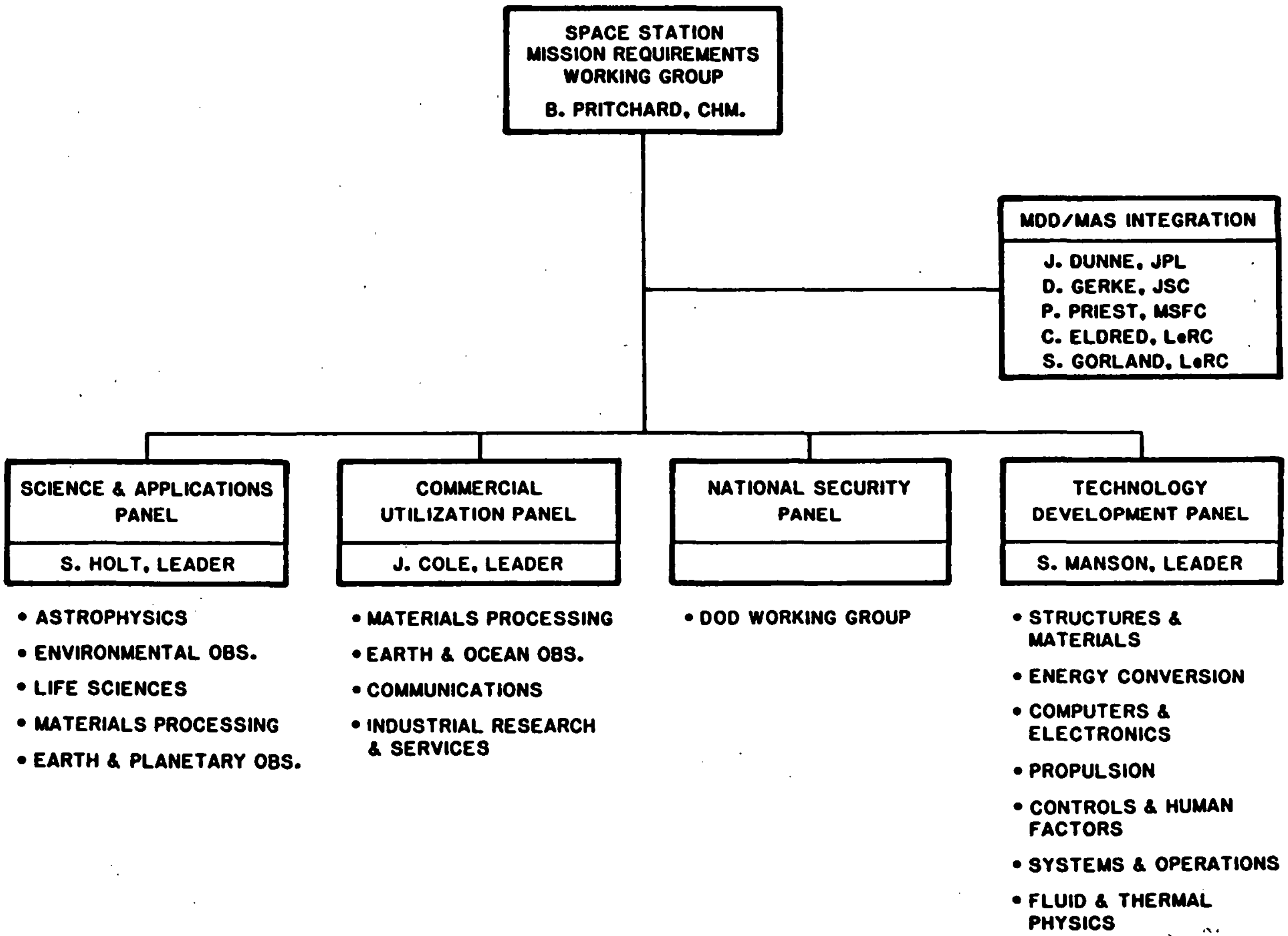
A NASA Mission Requirements Working Group was established on July 9, 1982. Membership for the Working Group was drawn from NASA Headquarters and Centers. The organization and membership of the Working Group is shown in Figure 2-1. Four panels reporting to the Working Group were also established. Each panel is led by a Working Group member.

The purpose of the Working Group is to: (1) oversee the contract studies; (2) ensure that comprehensive and parallel in-house studies were carried out; (3) exchange output data from the studies with the international community; (4) integrate the mission requirements defined in these studies into time-phased mission models; (5) prepare the Mission Description Document (MDD) that serves as the basis for the development of systems requirements that must be met by the Space Station; and (6) provide mission information to be used in Space Station conceptual design.

Each of the four panels listed in Figure 2-1 was assigned the task of analyzing requirements in their particular mission category to ensure that the mission and associated requirements were scientifically committed and/or technologically important and had a solid base of user support within the

FIGURE 2-1
MISSION REQUIREMENTS WORKING GROUP

ORGANIZATION



appropriate community. Organization and membership of the panels are described in Figure 2-2.

The Air Force, in its capacity as executive agent for the Space Transportation System (STS), has principal responsibility within the Department of Defense for the National Security portion of this study effort. This function includes defining military space missions, security guidelines, intelligence assessment, and appropriate utility guidance on contractor mission concepts. Oversight of these activities is being provided by representatives from the Air Force Space Division, the Navy, the Army, the Defense Advanced Research Projects Agency, the Air Force Space Command, the Air Force Systems Command, the Strategic Air Command, the Tactical Air Command, the Secretary of the Air Force for Space Systems, the Air Staff, and the Office of the Under Secretary of Defense for Research and Engineering.

Principal authority for coordinating the National Security effort and providing an interface with the study contractors and technical support has been delegated to the Space Division's Office of Plans (SD/XR). This office has formed a working group at Los Angeles Air Force Station, California. Membership in this working group is depicted in Figure 2-2.

The Mission Requirements Working Group and its associated panels initially provided a broad base of potential missions for consideration by the contractor teams and further analysis by the panels. Upon completion of the contract and international studies and the extensive parallel in-house analyses, the Working Group and its panels reviewed the results, integrated them by mission category, established missions by integrating payload elements as necessary, and summarized them. The missions were then divided into the following categories: Manned Space Station missions; low Earth orbit (LEO) Free-Flyer missions; LEO Space Platform missions; and high Earth orbit (HEO), geosynchronous Earth orbit (GEO), and planetary missions. Once the missions were categorized in terms of Space Station functional capabilities, scenarios were established. The categories were iterated against the mission requirements to capture all feasible requirements/capabilities scenarios. For final analysis, the to be determined (TBD) scenarios described in Section 5 were selected.

FIGURE 2-2

SPACE STATION MISSION REQUIREMENTS WORKING GROUP PANELS

SCIENCE AND APPLICATIONS PANEL

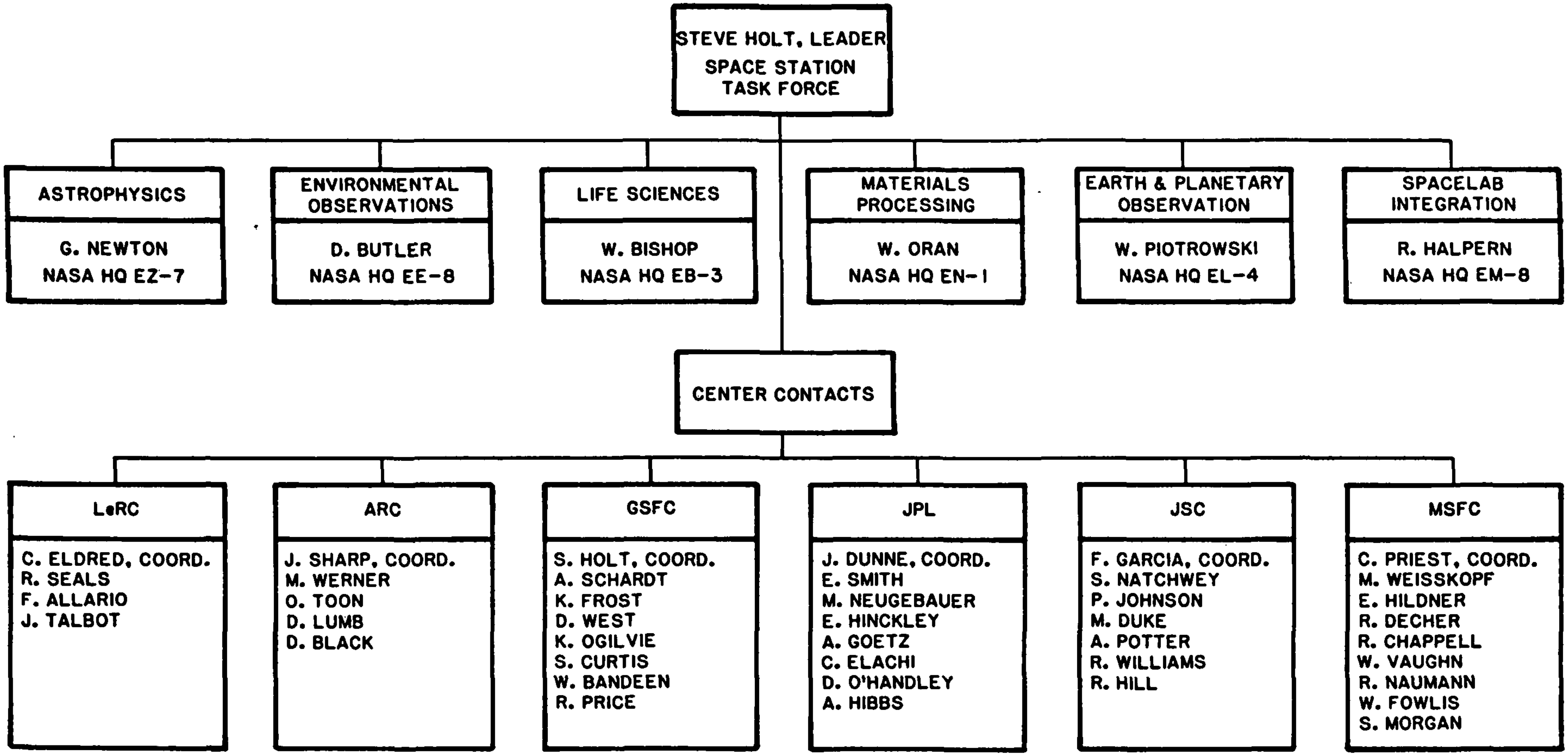


FIGURE 2-2

SPACE STATION MISSION REQUIREMENTS WORKING GROUP PANELS (Continued)

COMMERCIAL UTILIZATION PANEL

JOHN COLE, LEADER
SPACE STATION TASK FORCE

MATERIALS PROCESSING COMMITTEE
- C. YOST, NASA HQ/EN-1
- H. ATKINS, MSFC
- K. DEMEL, JSC
- R. JOHNSON, ARC
- K. TAYLOR, MSFC

EARTH & OCEAN OBSERVATIONS COMMITTEE
- W. ESKITE, NOAA
- H. MOORE, NOAA
- H. GUIN, NSTL
- W. STEPHENSON, JSC
- R. ANGLIN, JPL
- R. BERANEK, MSFC

COMMUNICATIONS COMMITTEE
- J. RAMLER, LeRC
- M. ENGERT, JSC
- F. CEPOLINA, GSFC
- R. DURRETT, MSFC

INDUSTRIAL RESEARCH & SERVICES COMMITTEE
- R. PHILLIPS, NASA HQ/LG-2
- S. GOLDBERG, HQ/LGE-2
- M. SMITH, HQ/OE
- O. SMISTAD, JSC
- R. NUNAMAKER, AMES

TECHNOLOGY DEVELOPMENT MISSIONS PANEL

SIMON MANSON, LEADER
NASA HQ/OAST/RSS-5

- B. ASKINS, MSFC
- W. WALES, MSFC
- D. ENNIS, ARC
- F. GARCIA, JSC
- T. LABUS, LeRC
- B. LIGHTNER, LARC
- J. RANDOLPH, JPL
- D. SUDDETH, GSFC
- G. BARNHARD, GSFC

NATIONAL SECURITY PANEL

TBD

With the definition of reasonable capability scenarios, it was possible to begin development of realistic, time-phased mission models. First, all mission requirements accommodated by a given operational capability scenario were established. Missions were then time-phased according to the following criteria:

- Logical scientific, commercial, or technical sequence;
- Fiscally reasonable NASA budget levels; and
- Technology maturity required to accomplish the mission.

2.1.2 Studies Of Space Station Needs, Attributes, And Architectural Options

Eight parallel, contractual studies were initiated on August 20, 1982, with the following companies:

- Boeing Aerospace;
- General Dynamics;
- Grumman Aerospace;
- Lockheed Missiles and Space Division;
- Martin Marietta;
- McDonnell Douglas;
- Rockwell International; and
- TRW.

The purpose of these studies, as stated in the RFP, were: Each contractor was directed to "devote approximately 60 percent of his efforts to the definition of user missions and their associated requirements, approximately 30 percent to the definition of Space Station functional architecture to meet those requirements and the associated benefits, and approximately 10 percent to rough order of magnitude costs associated with the architecture." As noted previously, the results of these studies, which were completed on April 20, 1983, were integrated with the results of in-house and international studies by the Mission Requirements Working Group and its panels.

2.1.3 International Mission Analysis Studies

Parallel studies were undertaken by the international community. Those governmental organizations conducting mission requirements studies and their associated governmental agencies and industrial contractors are listed in Figure 2-3.

Data exchanges between the U.S. and the international community occurred at the mid-term and at completion of the studies to ensure that international participation in the Space Station program was an integral element in the development of the total mission requirements that must be accommodated by the Space Station.

2.2 MISSION DATA BASE

The data sources for the mission requirements given in Section 3.0 are described in this section for the four mission classes (Science and Applications, Commercial, Technology Development, and National Security).

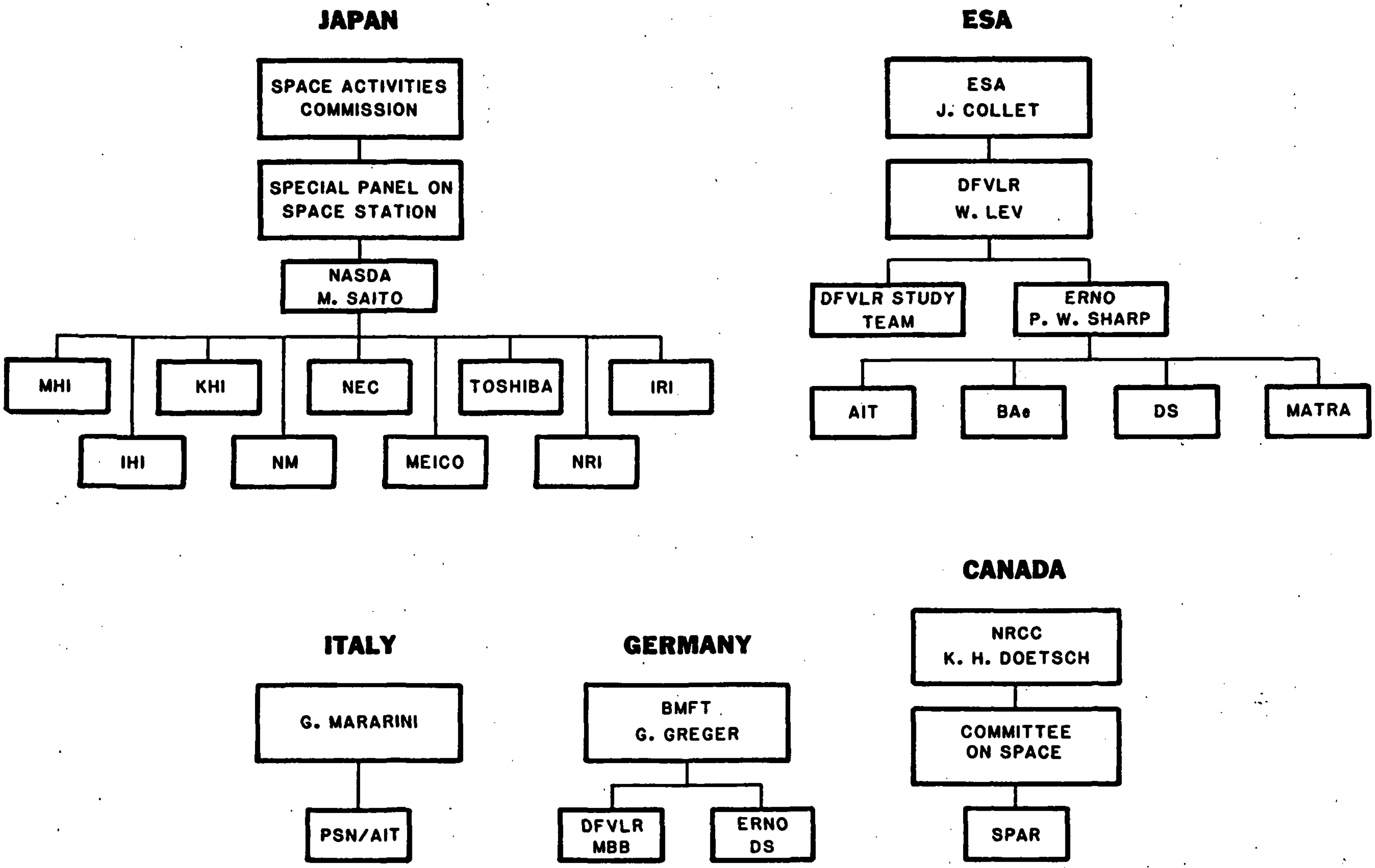
2.2.1 Science And Applications Missions Data Base

The Science and Applications data base was developed iteratively with the formal and informal participation of scientists throughout the potential user community.

Chronologically, the activity began with the formation of a team of representatives from each scientific program division in the Office of Space Science and Applications (OSSA). This group, hereafter referred to as the "panel," was chaired by Dr. Stephen S. Holt and was responsible for the initial generation, iteration, and maintenance of the data base throughout the duration of the exercise. Scientists at the NASA Centers, provided the necessary resources and expertise to aid in determining specific parametric requirements and provided valuable writing and editorial contributions. Those formally associated with the activity were named in Figure 2-2, but the panel acknowledges the informal contributions of many other interested NASA scientists, engineers, and managers.

FIGURE 2-3

INTERNATIONAL MISSION ANALYSIS STUDY ORGANIZATIONS



The panel began by generating a first encyclopedia data base consisting of all current plans and studies consistent with the overall scientific objectives of each discipline without regard to how relevant they were to any potential Space Station architecture. This first data base, therefore, consisted of the largest possible "wish list" and the totality of detailed, parametric requirements generated in previous studies (e.g., Space Platform). It was forwarded to the NASA Centers for comments and suggestions for identifying those elements in the encyclopedia data base that would be most appropriate for a Space Station system. With these and any other suggestions, the panel would exercise its own judgement in generating a first draft data base three months after establishing the encyclopedia base.

Soon after the start of the activity, the Space Science Board and the Space Applications Board reviewed NASA's approach to Space Station planning. In essence, both Boards recognized that a large fraction of the anticipated near-term Science and Applications program could be accomplished without a Space Station, but that a Space Station could significantly enhance that program. In particular, the prospects for a permanent, habitable environment, frequent experiment servicing, and construction and staging of very large space structures allowed completely new capabilities that were not previously available.

Recommendations from the panels of the Space Applications Board were available for the first draft, and recommendations from subcommittees of the Space Science Board were available soon after the generation of the first draft. These, in addition to a second round of NASA Center reviews and participation by outside-NASA scientists, provided the material for the second draft two months after the first. This second draft was utilized in detail by the systems requirements group.

The second draft was widely circulated among NASA's scientific advisory groups. Additional recommendations from the advisory groups, the Mission Analysis Studies contractors, and the OSSA were incorporated into a third draft that was issued three months after the second.

2.2.2 Commercial Missions Data Base

The information presented in the commercial section of this document was drawn from the experience of the members of the Commercial Utilization Panel and their colleagues, from numerous papers and presentations by the National Oceanic and Atmospheric Administration (NOAA) and NASA, from numerous contractor studies, and from discussions with contractors and investigators.

In the Earth and ocean observation area, some of the reference sources include:

- "Commercialization of the Civil Space Remote Sensing Systems" by John H. McElroy, NOAA, August, 1982.
- Private Sector Investment Study by NASA, 1979.
- "Encyclopedia of Environmental Science" by McLean, 1980.
- "20 Years of Weather Satellites," RCA, Schnapt, May, 1980.
- "Stereo Sat - A Private Joint Venture," Anglin, 1980.
- "Land Sat - A Proposed Commercialization Plan," Simmons, July, 1982, NASA/OSSA.
- "The Use of Satellite Observations of the Ocean Surface in Commercial Fishing Operations," D. R. Montgomery, JPL, 1980.

For the communications area, some of the reference sources include:

- "Financial Study for a Satellite Land Mobile Communications System," Corporate Finance Division of C. T. Bank N.A., for JPL, December, 1982.
- "Experimental Geostationary Platform System Concepts Definition Study," GDC, June, 1982.
- "The INMARSAT System and Its Future Development," T. Takahashi, AIAA 9th Communications Satellite Systems Conference, March 7-11, 1982.
- Comsat Communications Satellite Corporation Magazine, Vol. 2 - 1981 and Vol. 7 - 1982.
- "Task II Report Planning Assistance for the 30/20 GHz Program," World-Wide Satellite Market Demand Forecast, NASA, CR #167918, June 19, 1981.

- Satellite Week, April 5, 1982.
- Federal Communications Commission Memorandum, CC Docket No. 82-45, "Domestic Fixed Satellite Transponder Sales," August 17, 1982.
- "Costs of Communcations Satellites," S. Fordyce, Future Connections, Vol. 1, #2, November, 1981.
- "Trends in Commercial Communications Satellites," Proposed AIAA Paper, R. Lovell and S. Fordyce.

In the materials processing area, some of the reference sources include:

- Materials Experiment Carrier Studies by TRW, 1978 through 1980.
- "Early Usage of Space Policy," Frosh, June, 1979.
- "Guidelines for Materials Processing in Space Joint Endeavors," Frosh, 1979.
- Joint Endeavor Agreement with MDAC.
- Joint Endeavor Agreement with GTI.
- "Avenues and Incentives for Commercial Use of a Low-Gravity Environment," Brown and Zoller, September, 1981.
- "Advantageous Uses of a Manned Space Station for Science and Applications," JSC, August, 1982.
- GAO Report on Foreign Technologies, 1980.
- "Government-Industry Cooperation Can Enhance the Venture Capital Process," GAO Report to Senator. Lloyd Bentsen, GAO/AMFD/82/35, August, 1982.

2.2.3 Technology Development Missions Data Base

A technology development (TD) mission is an experimental project that is aimed at advancing space technology and is conducted with support from the Space Station. The scope of TD missions is very broad with value for science, applications, commercial uses, national defense, and enhancement of NASA's capabilities and role in space.

TD missions as defined here are not projects to develop enabling technology for the first Space Station. However, with support from the first or subsequent Stations, they would develop technology for modified or later generation Stations.

TD mission requirements influence the design of the Space Station that will support them. They will influence the design of the first Space Station.

Candidate TD missions were initially identified through their need for elements of the space environment plus one or more of the operational conditions made available by the Space Station. Operating conditions offered by the Space Station are:

- Space environment (low gravity, low pressure, low temperature, plasma, radiation);
- Human interface/experiment accessibility;
- Ability to handle large size (with extravehicular activity [EVA] and manned maneuvering units [MMU]); and
- Long-term operations capabilities:
    - -- Iterative adjustment/testing;
    - -- Evolutionary development (e.g., optimal environmental control and life support system [ECLSS]);
    - -- Long duration exposure, removal, inspection, or replacement; and
    - -- Other.

Candidate technology development missions were then reviewed for feasibility using alternate approaches (Space Shuttle, Long Duration Exposure Facility [LDEF], free-flyer, or other alternatives). When alternative approaches are viable, comparison studies are required based on cost, schedule, environmental impact, or other major criteria to determine whether they are appropriate as a Space Station mission. In the initial effort, screening was done qualitatively, not on the basis of detailed calculations. As a result of such screening, sixteen (16) candidate tasks were excluded on the basis that they could be done using the Space Shuttle. No calculations were made to investigate whether it might be more economical to perform those 16 tasks with the Space Station instead of with the Shuttle. Cost comparison calculations in such cases would be desirable.

The technology development tasks described in this document were prepared primarily by the technical staff of the NASA Field Centers. A number of additional tasks were obtained from the mission sets defined by the contractor and international study group organizations. A primary source that was employed for classification and assessment of the technology tasks was the NASA document entitled, Space Research and Technology Program and Specific Objectives, "Office of Aeronautics and Space Technology, Fiscal Year 1983."

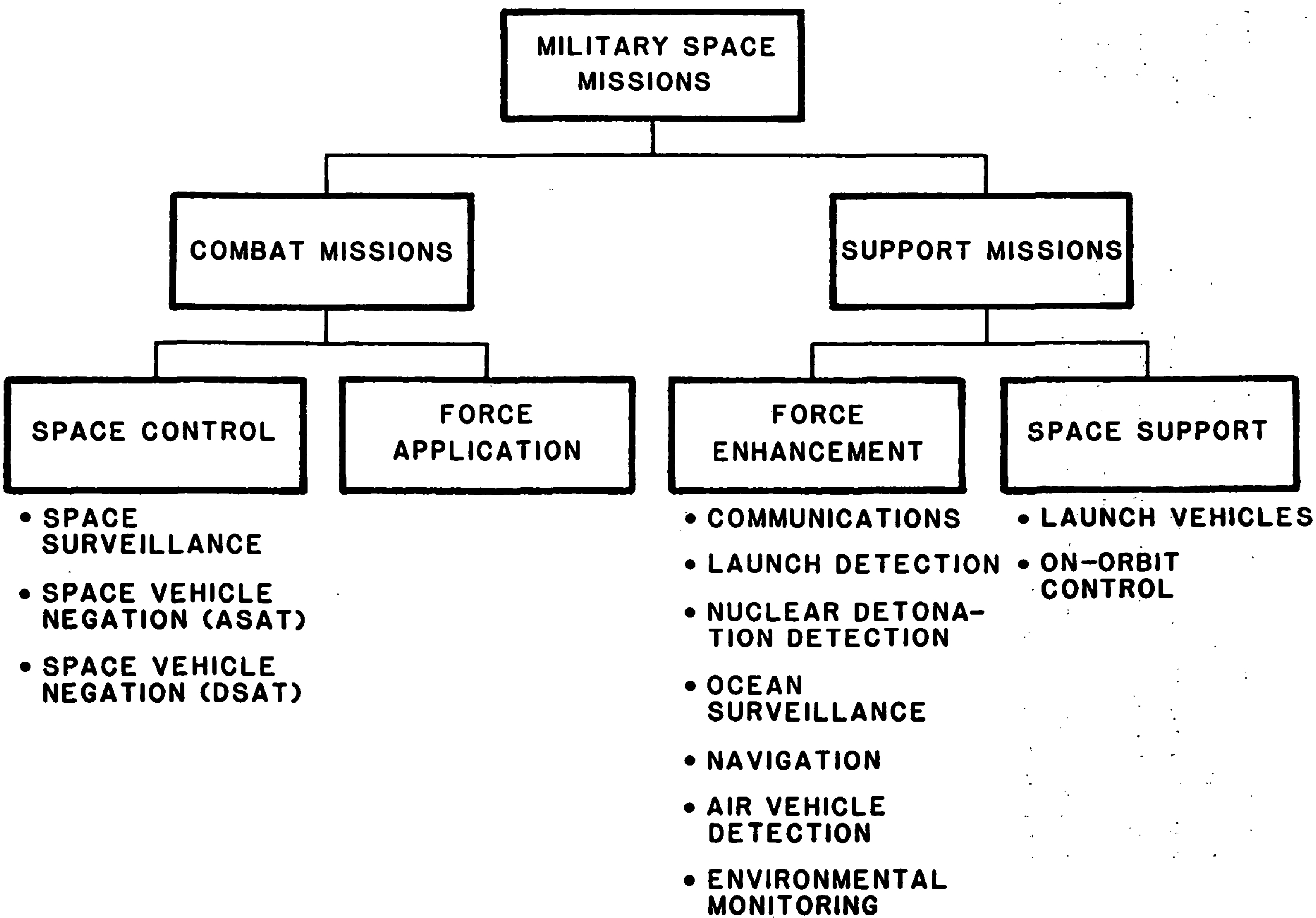
The activity was initiated by forming a panel of members of the staff of NASA Field Centers and NASA Headquarters. The panel members then conducted surveys of the technical personnel of their respective Centers to identify space technology tasks that would either require or significantly benefit from the services of a manned Space Station.

Seventy (70) technology tasks in space were proposed that reflected perceived future needs. Of these, 54 were retained. The 54 were then assembled into a draft volume that was distributed at the orientation meeting held for the Mission Analysis Studies contractors during September, 1982. Subsequently, the 54 tasks were grouped by technology discipline and presented with brief discussions in a second draft report. The present document contains all the tasks of the previous draft and adds supplementary tasks that have since become available from the NASA Field Centers and from the contractor and international study groups.

2.2.4 National Security Missions Data Base

National security space missions fall into two general areas: (1) combat missions; and (2) support missions. There are two further categories under each of these missions. Combat missions are divided into space control (which includes space surveillance and space vehicle negation [ASAT], and force application. Support missions are divided into force enhancement (which includes communications, launch detection, nuclear detonation detection, ocean surveillance, navigation, air vehicle detection, and environmental monitoring), and space support (which includes launch vehicles and on-orbit control). These missions are shown schematically in Figure 2-4. In each of these mission areas, research and development in space may be required before a commitment to operational missions.

FIGURE 2-4
MILITARY SPACE MISSIONS



3.0 USER MISSION DESCRIPTION/SUMMARY REQUIREMENTS

This section presents a summary of missions and high level requirements identified by user representatives in the major categories of Science and Applications, Commercial, Technology Development, and National Security. Detailed discussions of the user needs and programmatic plans from which these summary descriptions have been derived will be published as Volumes 2-4 of this document. The sources for this information are discussed in a generic sense in Section 2 of this document, and detailed references are given in the separate volumes. In this section, only those mission categories that can benefit from the existence of an operational Space Station system are described. In each case, the type of support required of that system is indicated and the level of need for the services is roughly characterized.

Acronyms used in this section are defined in Appendix A.

3.1 SPACE SCIENCE AND APPLICATIONS

3.1.1 Introduction

Space science and applications is NASA's program to advance scientific understanding and potential economic activity by exploiting the spacefaring capabilities being developed by the rest of the Agency. In developing the mission model, the existing structure of the NASA Office of Space Sciences and Applications (OSSA) was used as an organizing structure. This structure includes:

- Astrophysics - the study of the universe and of the sun as a star;
- Solar System Exploration - the study of the planets and their environment;
- Earth Science and Applications - the study of the planet Earth including the dynamics and interaction with the sun;
- Life Sciences - the study of life as it is affected by its environment in space, on Earth, and on other worlds;
- Materials Sciences - the study of the production of special materials and processes in the absence of gravity; and

- o <u>Communications</u> - the study of new, space-based communications techniques.

Together, these activities make use of four classes of capabilities that could be supplied by the Space Station. These are: (1) a pressurized laboratory (i.e., zero-gravity manned); (2) a base for attached payloads (e.g., sensors); (3) a servicing station for associated free-flyers; and (4) a jumping-off place for various other locations in space.

3.1.2 Basis And Rationale For The Mission Model

Based on years of planning and advice from advisory committees, the OSSA has a well-developed program plan for the future in most areas. The mission model given below is based on that plan. Three fundamental assumptions for the model were made; namely:

- The model would implement the current OSSA program plan using Space Station elements as appropriate.
- NASA would augment the OSSA program plan to capitalize on unique opportunities offered by a Space Station (e.g., life sciences, materials processing, experiments/developments requiring manned interaction or large scale resources).
- The projected program should be based on reasonable resource projections for existing programs (not including new program areas and the cost of the platforms themselves).

While the mission set is ambitious, it is constrained (particularly for free-flyers). For areas other than life sciences and materials processing, the mission set is a slight augmentation to the current long range plan. For life sciences and materials processing, the Space Station enables important new programs. The Platform/Space Station is enabling for some Earth/sciences missions in that it will provide large mounting areas, high power levels, etc., to simultaneously operate a large array of instruments.

The heritage for the mission elements and the model given below is rich. Most of it is already in the OSSA long range plan. In addition, the recommendations of the Space Applications Board (SAB) 1982 summer study are incorporated. Studies over the years of space platforms (by Teledyne Brown, TRW, the NASA Marshall Space Flight Center [MSFC] study on life sciences, and by scientists at the "Wheeler Workshop") have given a firm conceptual base for much of the model. Finally, extensive use of the concepts (and many of the details) derived by the eight mission analysis contractors was made. Listed below are the key studies that provide the intellectual and planning basis for the model.

- Astrophysics:
  - Field committee report;
  - CSSA/CSSP reports; and
  - Specific mission studies.
- Solar System Exploration:
  - SSEC core program;
  - Potential core program augmentation;
  - Space Station utilization study; and
  - Specific mission studies.
- Earth Science and Applications:
  - Five year plan;
  - Earth sciences platform study;
  - SAB summer study; and
  - Specific mission studies(e.g., UARS, Open Topex).
- Life Sciences:
  - MFSC platform study;
  - Life sciences Space Station users workshop;
  - Space Station utilization study by Johnson and Kennedy Space Centers (JSC, KSC, respectively);
  - Fabricant report; and
  - LSAC reviews.

- Materials Processing in Space:
  - -- Materials processing working groups (USRA);
  - -- Commercial materials processing workshops (TRW);
  - -- Harvard MBA/creative marketing studies; and
  - -- SAB summer study.
- Communications:
  - -- Commercial opportunities report;
  - -- Communication Space Station workshop at Lewis Research Center (LeRC); and
  - -- SAB summer study.

In short, we are confident of the validity of the elements of the model and in general the rationale for the phasing.

3.1.3 Mission Elements

The categorization of science and applications disciplines corresponds to their program responsibility in the NASA Office of Space Science and Applications (Astrophysics, Earth Science and Applications, Solar System Exploration, Life Sciences, Materials Processing, and Communications).

As such, the potential mission elements addressed are categorized operationally rather than from the point of view of the most fundamental scientific problems to which they can be addressed (e.g., "X-ray astronomy" rather than "galaxy formation"). In many cases, one operational discipline plays the major role in addressing a fundamental scientific problem, but in many other cases, our perspective has matured to the point where the problems require the coordinated application of several techniques for adequate study. Some problems even require a mixture of observational classes (e.g., the effective study of solar-terrestrial interactions requires the combination of celestial-pointing [solar], Earth pointing [both nadir and limb], and in situ [plasma probe] observations for their proper reconciliation). Depending on the problem, the most desirable experimental approach may be an individual instrument, a large "observatory," which accommodates a variety of different complementary investigations (the Earth Science Research Mission), or the operational coordination of investigations that are physically remote from each other. Therefore, the scientific priority of the fundamental problems to be addressed by individual investigations and by combinations of investigations should be an important consideration in the determination of the architecture of a Space Station system that will host the means by which the research will be conducted.

The typical requirements associated with instrumentation characteristics of each of the discipline areas are indicated in Table 3-1. A brief overview of the general scientific objectives and how they may be addressed with space observations are identified in the following sections.

3.1.3.1 Astrophysics

This general area of research deals with the study of the cosmos. The targets of detailed scrutiny range (in distance from the Earth) from the sun to quasars at the edge of the observable universe. Its overall objectives are to investigate the physical laws and their specific manifestations that are operable in celestial systems which are as small as collapsed dead stars and as large as the universe itself.

Space-based observations are necessary for this study because most of the essential observations cannot be made from under the opaque blanket of the Earth's atmosphere. With the exception of charged particle measurements of the cosmic radiation (which cannot reach the Earth without catastrophic interaction in the atmosphere), astrophysics measurements are almost entirely confined to electromagnetic radiation. Of the twenty-two decades of the electromagnetic spectrum potentially available for study, only five can be observed from the ground; four decades at radio wavelengths, and one in the visible band. Gravitational astrophysics in a mode which either investigates the very nature of the gravitational interaction (i.e., general relativity) or interrogates the sky for gravitational radiation from specific objects, generally requires a degree of isolation which makes it unsuitable for attachment (or even in low Earth orbit, in many cases).

TABLE 3-1
TYPICAL DISCIPLINE MISSION REQUIREMENTS

	ORBIT INCLINATION	ORBIT ALTITUDE	POINTING DIRECTION	POINTING ACCURACY	ASPECT ACCURACY	DATE RATES	POWER	MASS	SERVICE INTERNAL	MAJOR SUSCEP.
UV-OPTICAL ASTRONOMY	L	L	C	M	S	M	M	M	M	E,P
IR-RADIO ASTRONOMY	I	L	C	M	S	I	L	L	M	E,P,R
X-RAY ASTRONOMY	L	L	C	M	S	M	M	H	M	P
GAMMA-RAY ASTRONOMY	L	L	C	M	S	L	L	M	M	M,P
COSMIC RAY ASTROPHYSIC	L	X	X	X	D	L	L	H	M	M
SOLAR PHYSICS	H	H	S	S	H	M	L	L	M	E,P
SPACE PLASMA PHYSICS	H	H	C	D	M	L	L	L	M	P
ATMOSPHERIC COMPOSITION	H	H	E	M	S	L	M	M	M	E
ATMOSPHERIC DYNAMICS	H	H	E	M	S	L	M	M	M	E
OCEANS	H	H	E	D	M	L	L	L	M	R,E
OPER, CIVIL ACTIVITIES	H	H	E	M	M	I	L	L	M	E
EARTH RESOURCES	H	H	E	D	M	H	L	L	M	R,E
GEOSCIENCES	H	H	E	S	H	U	H	H	M	R,E
SOLAR SYSTEM MISSIONS	L	E	X	X	X	L	L	L	X	X
MATERIALS PROCESSING	X	X	X	X	X	V	L	L	H	G
LIFE SCIENCES	L	X	X	X	X	V	L	L	C	G
COMMUNICATIONS	L	E	X	X	X	L	L	L	X	X

ORBITAL INCLINATION: L (low, 30°), H (high, 60°), I (intermediate).

ORBITAL ALTITUDE: L (low, 500 km), H (high, 500 km), G (geosynch), E (apogee 10^4 km).

POINTING DIRECTION: C (celestial), S (solar), E (earth).

POINTING ACCURACY (a priori): S (arc sec), M (arc min), D (degree or more). This represents the accuracy necessary to maintain the target within the instrument field-of-view.

ASPECT ACCURACY (a posteriori): H (0.1 arc sec), S (arc sec), M (arc min), D (degree or more). This specification is not independent of jitter or data rate, insofar as it represents accuracy to which each event can be labeled.

DATA RATES (in Mbps): U (100), H (10–100), I (1–10), M (0.1–1), L (0.01–0.1), A (0.01), V (additional video req'd).

POWER (in kw): H (5), M (1–5), L ( ).

MASS (in 1000 kg): H (5), M (1–5), L ( ).

SERVICE INTERVAL: M (monthly), W (weekly), D (daily), H (hourly), C (continuously).

MAJOR SUSCEPTIBILITIES: P (pointing disturbances), M (mass proximity; e.g., for gamma-ray background), E (effluents; e.g., for cold surfaces), R (RFI), G (g-levels 0.001 g).

FOR ALL CATEGORIES, THE SYMBOL "X" MEANS THAT THERE IS NO SPECIFIC REQUIREMENT FOR THAT DISCIPLINE.

Astrophysics observations generally require precisely-pointed telescopes and favor low-altitude, low-inclination orbits to minimize the detector backgrounds that arise from the ambient radiation environment.

3.1.3.1.1 Astronomy (UV, Optical, Infrared, and Radio).

UV and Optical Astronomy (ST, FUSE, Starlab) - The primary objective of UV and optical astronomy is the observation of light from stars and nebulae as it passes through the gas and dust in interstellar and intergalactic space to reach the Earth. The spectra of transmitted and absorbed light indicate the physical conditions in the source and in the medium through which the light has traveled. The light is also imaged to observe the structure of galaxies and regions where stars are being born and where they are dying. Quasars and pulsars are two examples of compact sources very different from ordinary stars that emit UV and optical (visible) light.

UV and optical radiation must be observed from above the atmosphere for different reasons. UV is completely absorbed in air, while optical is only scattered. This scattering, however, prevents sub-arc-second viewing from the ground.

Free-flying UV and optical telescopes will need servicing in orbit. The Space Telescope (ST) is being built so that instruments and several other major systems can be changed in orbit by a team of astronauts. A Space Station in orbit at a 28.5 degree inclination must be capable of servicing the Space Telescope. Future UV and optical telescopes such as the Far Ultraviolet Spectroscopy Explorer (FUSE) and Starlab can certainly be operated as serviceable free-flyers, but it is conceivable that they might be more directly associated with the Space Station in an attached mode if their pointing and contamination requirements can be met. An option under consideration is to first fly Starlab attached to the Shuttle and subsequently mount it on a Space Station for long-term observations.

Infared and Radio Astronomy (OLVBI, LDR, SIRTF) - The objectives of infared and radio astronomy are largely connected to the processes of birth in the universe, from the Big Bang which marked its creation to the formation of stars and planets out of the gas and dust in galaxies. Infared astronomy cannot be performed from the ground for wavelengths between approximately 30 microns and 1 millimeter. Radio astronomy is especially sensitive for investigating relativistic electrons in quasars, pulsars, radio jets from galaxies, and active galactic nuclei. By combining signals from widely separated telescopes, a technique known as Very Long Baseline Interferometry (VLBI), the performance of a single telescope the size of the separation between the telescopes can be simulated. Using an array of Earth-based telescopes and one in orbit (orbiting VLBI or IVLBI), the performance of a radio telescope the size of the Earth can be synthesized.

The Earth's atmosphere is relatively transparent to radio so OVLBI is the primary reason to pursue radio astronomy from space. In the infared, however, only a very small fraction of the radiation incident on the top of the atmosphere can get through, and then only at a small sample of wavelengths. The major free-flying mission of the 1990s in the infared will be the Large Deployable Reflector (LDR). Because LDR will be passively cooled, it prefers a high inclination to reduce the thermal load. Without assembly in space or man-assisted deployment, it is unlikely that LDR can be larger than approximately 10 meters in diameter.

Orbiting VLBI and the Shuttle Infared Telescope Facility (SIRTF) have been defined to be supported by the Shuttle as Spacelab missions. In order to observe for longer periods and with greater sensitivity, investigations could be performed from an unmanned platform serviced by the Shuttle or the Space Station. It is conceivable that they might be attachable to the Space Station, but the cryogenic optics of SIRTF present a severe contamination problem.

3.1.3.1.2 <u>High Energy (X-Ray, Gamma-Ray, Cosmic-Ray)</u>.

<u>X-Ray Astronomy (XTE, AXAF, HTM, LAMAR)</u> - The main objective of X-ray astronomy is the investigation of high energy processes in all astrophysical systems, including the very compact sources associated with neutron stars and black holes. The wavelengths correspond to the sizes of atoms and detection is usually accomplished by counting photons: Discrete, quantized packets of

radiation carrying an energy proportional to the frequency of the radiation. The energies of X-ray photons lie between 0.1 kilo-electron volt (KeV) (soft X-rays) and 100 KeV (hard X-rays), and no X-rays are capable of traversing more than a small fraction of the atmosphere without total absorption.

The Advanced X-Ray Astrophysics Facility (AXAF) will be a mature observatory in the same class as Space Telescope. The AXAF, like the ST, will be built so that instruments at the focal plane and some of the more important facility subsystems can be changed in orbit. If there is a manned Space Station in orbit at 28.5 degrees, it will be required to service this important free-flying observatory. In addition to replacing instruments and modules, some instruments might require a resupply of cyrogens.

Another important future mission in X-ray astronomy is the High Throughput Mission (HTM) which could be similar to the Large Array of Modular Reflectors (LAMAR) defined as part of the Spacelab program. HTM, with very large area at moderate (approximately 1 arc minute) angular resolution, is necessary for investigations of the faintest and most rapidly varying sources.

Gamma-Ray Astronomy (GRO, HRS) - Gamma-ray astronomy investigates the physical condition in the most energetic environments in the universe. The wavelength of gamma-radiation is typically the size of the nucleus of an atom or smaller, and, like X-rays, gamma-rays are observed by counting photons. Gamma-ray photons have energies about 100 KeV, and can be observed from above the atmosphere only. At energies above 10 giga-electron volts (GeV), gamma-rays can produce a measureable shower of secondary particles in the atmosphere which may allow the detection and crude characterization of the incident gamma-ray from the ground.

The gamma-ray telescope and other systems on the Gamma-Ray Observatory (GRO) that will be in orbit at 28.5 degrees inclination are being designed to be serviceable in orbit by a team of astronauts. In the future, a gamma-ray telescope system with high spectral resolution will be developed to investigate the information about nucleosynthesis in the galaxy contained in narrow gamma-ray lines of naturally radioactive elements. The energy range between

100 KeV and 10 megga-electron volts (MeV) contains these lines. Like the other future missions in astrophysics, the High Resolution X-Ray and the Gamma-Ray Spectrometer (HRS) can be accommodated on a free-flyer and serviced by a Space Station.

Cosmic-Ray Astrophysics (SCRN, TRIC, HEIE) - While astrophysics generally deals with electromagnetic radiation as a means by which the cosmos can be interrogated, cosmic-ray astrophysics investigates the origin and propagation of massive, charged particles that move close to the speed of light. Charged particles are deflected as they move through magnetic fields, but the more energetic they are the larger their radius of curvature. The Earth's magnetic field keeps cosmic rays with energy less than 15 GeV from reaching the Earth's equator, but the field is very weak over the magnetic poles allowing low energy cosmic rays to reach the top of the Earth's atmosphere at high latitudes (they do not survive to the ground, however).

Most cosmic rays are the nuclei of atoms that have been stripped of their electrons and accelerated to energies which are measured in giga-electron volts (GeV) and tera-electron volts (TeV) -- billions and trillions of electron volts. For comparison, their rest masses are approximately 1 GeV per nucleon so they are truly relativistic.

The main objective of cosmic-ray astrophysics is to find out how the particles received their enormous energies. This can be investigated by observing the elemental composition (which should reflect the composition at the source with suitable modifications for transit) and by measuring the energy spectra (which should reflect the physical processes responsible for the acceleration). Except for a few abundant species (e.g., iron), the heavier and/or more energetic the nucleus, the rarer it is.

One way to measure the composition of ultra-heavy cosmic-rays is to utilize the Long Duration Exposure Facility (LDEF) to carry high resolution plastic track detectors into a high inclination orbit. Ultimately, plastic particle detectors may be assembled into a configuration giving 1 square kilometer of collecting area tc search for rare nuclei and exotic particles such as magnetic monopoles.

A cosmic-ray telescope is being developed for Spacelab 2 to study the elemental composition and energy spectra of cosmic-ray nuclei (SCRN) at high energies. SCRN will extend the spectrum of the most abundant elements (other than hydrogen and helium) up to an energy of 1 TeV to investigate the confinement of cosmic-rays in the galaxy. SCRN will be able to extend its observations to higher energies and rarer elements if it can be operated for a much longer time in space than the few weeks (at most) that it may obtain from repeated Spacelab flights.

Another experiment proposed for Spacelab, the Transition Radiation and Ionization Calorimeter (TRIC), is designed to observe protons, electrons, and helium nuclei to energies to 10 TeV from Spacelab, and 100 TeV from a year's operation in orbit. At the latter energies, observations of showers from the ground demonstrate that there is a significant change in the composition of cosmic-rays. It is a major objective of cosmic-ray astrophysics to find out the precise nature and origin of this anomaly. The isotopic composition at energies above 1 GeV can best be done with a long exposure from a high inclination orbit. The High Energy Isotope Experiment (HEIE) would have requirements similar to those of SCRN and TRIC, but the orbit must be inclined to at least 57 degrees.

Cosmic-ray investigations have the least restrictive pointing and contamination requirements of any discipline in astrophysics and should therefore be most easily accommodated in an attached mode to a resource-rich Space Station.

3.1.3.1.3 Solar Physics (SMM, SCDM, SIDM, SOT, ASO, POF). Solar physics investigates the motion of gas on the surface of the sun and the physical condition of gas above the surface to determine the internal structure of the sun, how it transports energy to the surface, how sunspots and flares are generated, how the corona is heated, and how the solar wind is accelerated. For UV, X-ray, and gamma-ray observations, or for information at resolution better than 100 kilometers in the optical, instruments must be carried above the Earth's atmosphere. A primary objective of solar physics is the ability to predict the times and places of major outbursts of solar activity.

Two missions are being studied which may be implemented as free-flyers: These are the Solar Corona Diagnostics Mission (SCDM) and the Solar Internal Dynamics Mission (SIDM). SCDM is aimed at determining the source of energy input to the corona, while SIDM will measure the flow of gas on the surface of the sun with high velocity resolution to determine the means by which waves propagate from within the Sun. From an orbit with many days of uninterrupted viewing of the sun, SIDM will be able to collect otherwise unavailable data about the internal structure and dynamics of the sun. SIDM would prefer, therefore, a solar synchronous (or perhaps geosynchronous) orbit, while SCDM will work very well from a 28.5 degree inclination.

The Solar Optical Telescope (SOT) is being developed as a Spacelab facility for imaging the solar surface with resolution of 100 km. Beyond the SOT Shuttle flights, it is anticipated that the SOT will evolve into the Advanced Solar Observatory (ASO) which will also contain complementary telescopes for hard X-ray imaging at high resolution and for imaging extreme UV and soft X-rays. The plan is to develop these instruments through the Spacelab program flying them first on sortie missions with the Shuttle. The ASO will observe with much higher resolution than can be obtained from the ground, and will also provide information about shorter-than-visible wavelengths. Since interactive operations may be required, its possible accommodation in a manned Space Station should be considered in addition to the option of a free-flyer.

3.1.3.2 Earth Science And Applications

This area of research deals with the study of Earth, including the solid body geophysics, the land, the fluid portions of the Earth's environment, and the sun as a source which derives most aspects of the environment. The fluid aspects are characterized by changes on timescales that are easily observable. The true test of man's understanding of the factors that govern the Earth's environment lies in his ability to successfully predict their phenomena and not to merely describe their current state. However, time scales of changes in the solid body are characterized by decades or centuries; thus some measurements over extended periods are feasible.

Space-based observations are essential to this study, mainly because of the breadth of the view available. Solar observations are mainly of the total output of the sun, which is better accomplished without the interference of an intervening atmosphere. Space plasma physics requires measurements which, to date, have necessitated flying through the region of the plasma that is to be observed. Indeed, this discipline was brought into being by the advent of rockets and spacecraft.

Two styles of observation are employed in measurements of the atmosphere and the oceans. First, satellites offer the only practical means of obtaining calibrated global measurements. In general, this is accomplished with quasi-polar, low Earth-orbiting spacecraft. Second, geostationary orbits offer the ability to make continuous measurements over a broad region of the globe. In general, the contributions that a low Earth-orbiting Space Station system can make to this latter category of investigation is through transportation, basing for servicing, on-orbit assembly, communications, etc. Both styles are considerably enhanced by the simultaneous, coordinated utilization of experiments in disciplines that are fundamentally interrelated. Therefore, multi-instrument facilities that include environmental and Earth science investigations are appropriate for the most definitive research.

In the 1990s, land observation programs could be enhanced significantly with specialized instrumentation and capability attached to a Space Station. Because of the synoptic, repetitive view from space, a Space Station with an Earth observing capability would enhance the study of the Earth. It would also enhance the development of space-related "tools" for such study by providing the opportunity to focus a large complement of instruments covering a broad range of the electromagnetic spectrum on particular aspects of renewable resources, the geosciences, and on the monitoring of episodic events and disasters. A Space Station in near polar orbit would offer the opportunity to address problems in the disciplinary areas on a global basis. A Space Station at a lower inclination would still offer the opportunity to conduct meaningful research across the range of Earth-observing disciplines, but not on a global scale.

3.1.3.2.1 <u>Space Plasma Physics (OPEN, STO, Space Plasma Lab)</u>. There are two main thrusts in the current space plasma physics program. First are the large-scale system studies utilizing free-flyers in order to understand the large-scale processes that control the Earth's near-space environment. This involves a series of free-flyers simultaneously measuring the energy input, the storage regions, and the discharge of energy towards the Earth. The second main thrust consists of active experiments of Spacelab where the processes that occur in plasmas are studies. This involves the injection of particle beams, electromagnetic energy, and chemicals, together with the appropriate diagnostics, to study their interactive processes in detail. OPEN requires a multi-year mission; the active plasma experiments are well-matched to one-week Spacelab flights.

The Space Station, because of its long flight time and its potentially large weight-carrying capability, can be utilized to perform studies of both types. Since the altitude range is limited, however, it is not capable of replacing missions like OPEN, but it can perform supporting studies and specific investigations not covered in the other projects.

Particularly suitable for Space Stations are continuous observations of the solar input to the terrestrial system in the ultraviolet, visible, and X-ray bands. The solar wind and the particle inputs will still need monitors outside the Earth's atmosphere. In addition, some "state-of-the-magnetosphere" observations can be made. Both the above, together with a real-time data system, can determine the best times for specific items like chemical releases, rocket launches, and multi-probe releases to answer very specific questions about the response of the magnetosphere to particular stimuli. In addition, detailed studies requiring high data rates for short periods of time are needed to resolve questions concerning the separation of seasonal from hemispheric anomalies in the atmosphere and ionosphere. These require the measurement of composition, concentration, and temperature as functions of time, height, and latitude.

The ability to carry wave and particle injectors also makes it possible to carry out active experiments with high selectivity when ambient conditions are suitable (e.g., unusually quiet or disturbed, pre- or post-substorm). Selective operations in the passive or active modes will help to answer important questions concerning the coupling between different regions of the solar-terrestrial system such as the atmosphere, ionosphere, magnetosphere, and heliosphere. These will require wave, particle, and chemical injections together with the reception of returned particle beams, the detection of stimulated emissions, and the measurement of perturbations of the three-dimensional distribution functions of the plasma components. Some of these measurements need to be made away from the Space Station because of the spatial variations expected. This leads to requirements for additional types of in-situ platforms associated with the Space Station (i.e., maneuverable, recoverable satellites, ejectable probes, and tethered sub-satellites) in addition to a large, multi-disciplinary platform at high inclination capable of addressing many of the aspects of the solar-terrestrial relationship (Solar Terrestrial Observatory).

3.1.3.2.2 Atmospheric Composition (LIDAR, ESR). The chemical composition, dynamics, and energetics of the atmosphere must be understood in order to assess and predict man's impact on his environment. Thus, the objective is to make quantitative measurements of the spatial and temporal variability of those constituents involved in atmospheric chemistry, such as nitrogen, hydrogen, chlorine, and sulfur compounds. The use of active and/or passive remote sensing with limb and nadir viewing geometries from a Space Station to probe the atmosphere with high spatial resolution, could provide the necessary global observations of these species, their distribution, sources, sinks, and variabilities, to make the desired assessments and predictions.

The use of a Space Station element for atmospheric composition measurements could capitalize on the unique capabilities of the lidar technique to probe the atmosphere with high spatial resolution providing global observations of selected species on a continuous (day and night) basis. In addition, such a lidar system could be used for other discipline objectives (e.g., atmospheric dynamics) by monitoring circulation of trace constituents and radiative balance by monitoring radiatively active constituents such as aerosols, water vapor, and carbon dioxide. A modular hardware approach could be adopted where individual lidar components are readily interchangeable and could be replaced in orbit to accommodate changing measurement objectives. For example, the telescope/receiver would be sized for optimum measurement sensitivity requirements with provisions made for changing the transmitter/lasers and detectors to accommodate spectral measurements from 0.2 to 12 microns, including the ability to accommodate on-axis cryogenic heterodyne detectors for far IR measurements. Periodic manned service in-orbit could then change components (i.e., reconfigure the system for multi-discipline objectives as well as provide routine maintenance such as cryogen replacement when such detectors were being used). In addition, in-flight adjustment of the laser beam divergence, receiver field-of-view, and alignment may be required to maximize signal-to-noise while maintaining eye safety. The frequency of such manned service would vary from twice per orbit for diurnal variability studies to once every several weeks for long-term trends or seasonal variability studies.

3.1.3.2.3 Atmospheric Dynamics And Radiation (ESR). Many of the problems that must be solved in atmospheric dynamics are global (i.e., events in the tropics influence mid-latitude weather several days later and a sea-surface temperature anomaly in the sub-tropical Pacific Ocean can have profound effects on the severity of the winter experienced by the eastern United States). Thus, the global observational capabilities offered by satellites provide a unique approach to solving these problems.

Remote sensing from space platforms has already shown great promise in providing measurements needed to describe phenomena ranging from individual thunderstorms to planetary scale circulations. Recent studies have demonstrated the positive impact of space-derived temperature soundings on numerical weather forecasts, but the quality of these remote temperature and wind soundings is not yet equivalent to that of conventional in-situ soundings and satellite observations of moisture are crude estimates at best. Advanced technology appears to be capable of providing remote soundings that surpass in-situ observations in quality, while retaining the vastly improved coverage that only satellites can provide. Satellite-derived observations will ultimately constitute the most effective and economical means of acquiring the data needed to describe atmospheric features ranging from mesoscale to planetary scale (10s to 1000s of km). It has also become clear that measuring a single parameter from space provides only part of the data needed to improve our understanding of atmospheric processes. The atmosphere, the oceans, and the land surfaces interact with each other requiring a multi-disciplinary approach to observing their behavior. Thus, atmospheric temperature, moisture (including precipitation), and winds respond to and alter the conditions on land and sea that drive the system.

Temperature and moisture soundings provided twice daily with global coverage would be used to define the initial state of the atmosphere in models ranging from mesoscale to planetary scale. With accurate observations and good coverage, the models will be able to provide accurate future states of the atmosphere. Present models handle moisture very poorly and rainfall is the most difficult parameter to predict. Accurate initializations and analyses will enable assessment of models, diagnose the behavior of the atmosphere, improve the physics included in the models to more realistically describe atmospheric behavior, and to determine which parameters are important and to what accuracy they must be measures. In addition, with the realistic models developed from a better observational capability, simulations can be run to define an optimum observing system(s).

3.1.3.2.4 Oceans (ESR, TOPEX). The broad objective is to develop space-borne techniques and to evaluate their utility for observing the oceans. Specifically, it is desired to determine the circulation, heat content, and horizontal heat flux of the global oceans, how they are influenced by the atmosphere and how they influence climate. It is desired to determine the primary productivity of the oceans, how it is influenced by ocean circulation and the atmosphere; and how it in turn influences the marine food chain, the rate of carbon dioxide uptake by the oceans, and climate. A third area of interest is the determination of the characteristics of the polar sea ice cover, how they are influenced by the atmosphere and the ocean, and how they in turn influence climate. In order to accomplish these objectives, several global ocean data sets of long duration, typically 3-5 years, are needed. Specifically, measurements of global sea height, sea surface wind vectors, chlorophyl concentrations, ice type and boundaries, and sea surface temperature are needed.

In terms of how specific discipline free-flyers might utilize a Space Station, the only free-flyer currently being proposed in support of oceans research is TOPEX. While it is assumed that TOPEX may well predate the Space Station, the Space Station could be used for on-orbit servicing to extend the data collection period well beyond the currently envisioned three years. This would be important for observing the longer-term variability of the oceans (i.e., the El Nino, which occurs every 3-8 years) as well as gaining insight into the impact on climate of ocean variability.

Beyond free-flyers and given that the requirements can be met by a Space Station (in particular, the requirement for global coverage), the Space Station would be a useful platform for the deployment of an operation of ocean sensors such as the Scatterometer, the Ocean Color Imager (OCI), the Synthetic Aperture Radar (SAR), and the passive microwave radiometer (possibly utilizing a large dish antenna for high resolution sea surface temperature). Additionally, the Space Station would make an excellent platform for the checkout and evaluation of new ocean instrument techniques such as those in the Ocean Microwave Package.

3.1.3.2.5 <u>Operational Civil Meteorological Activities (GEOS Follow-On)</u>. The role of civil operational meteorological satellites is to provide a means of obtaining quantitative environmental data and data-handling capabilities through the following:

- High resolution, day and night, cloud cover observations on a local and global scale;
- High resolution observations of sea surface temperatures;
- Observations of verticle-temperature and water-vapor profiles in the troposphere and lower stratosphere on a global basis;
- Observations of verticle-temperature profiles in the middle and upper stratosphere on a global basis;

- Operational flight of an ozone sounder for monitoring the vertical distribution of atmospheric ozone on a global basis;
- Operational flight of a high-capacity data collection/relay and platform location system; and
- Observations of electron and proton flux densities and total particle energy densities in the near-Earth space environment.

The polar METSAT mission requirements for the 1990s will be the same as for the present Tiros-N. Tiros-N, the prototype satellite system, and its operational follow-on satellites are designed to provide an economical and stable platform for the advanced instruments to be used in making measurements of the Earth's atmosphere, its surface and cloud cover, and the proton and electron fluxes near the Earth. As a part of this mission, the satellites also have the ability to receive, process, and retransmit data from free-flying balloons and buoys and remote automatic observation stations distributed around the globe, and track those stations that are in motion.

The Space Station could incorporate the instruments of one of the polar orbiting operational meteorological satellites and thereby replace that satellite. Another role would be to service meteorological satellites -- both the polar orbiting and the GEOS satellites in geosynchronous orbits. Supplanting the functions of the GEOS satellites would require a geostationary Space Station.

3.1.3.2.6 Renewable Resources (EST).

Vegetation Research And Monitoring. It is necessary to continue increasing the fundamental understanding of the biophysical and biochemical processes that affect remotely-sensed spectral signatures of vegetation in a manner that compounds accurate interpretation of remotely-sensed data.

Currently, several uncertainties exist in the estimates of the total amount of vegetative matter (biomass) on the surface of the Earth. This uncertainty exists because the areal extent and distribution of vegetative units (biomes) has not been measured, let alone monitored, for changes over time. The extent and distribution of biomass also determines the global surface albedo, an important parameter for determining the energy balance of the Earth. In order to determine vegetation resources available and trends in the vegetative changes on the surface, long-term, near-global data need to be acquired on the total resources. The measurement requirements necessitate observational data in the visible, near short, and thermal IR spectral regions at various look angles, slopes, azimuth, and elevation angles, throughout a full year's cycle under various atmospheric conditions for the purpose of that characterization over one complete cycle. For monitoring purposes alone, however, long-term (if not necessarily continuous) coverage is required.

The Space Station could provide extended observational opportunities from satellite orbital altitudes over virtually the entire vegetated land surface of the Earth over a variety of viewing conditions. The Space Station approach offers two additional advantages: (1) The opportunity to fly a full range of instruments that simultaneously view the same surface areas; and (2) the opportunity to alter instrument parameters and/or repair instruments through man-tending. With an appropriate choice of orbital parameters, the Space Station offers the advantage of acquiring observational data at the temporal frequency necessary as input for models used to forecast agricultural production and yield, for input to the decision process for ranchland utilization, and for input for managing timber harvests.

Land Cover Dynamics Research. Mankind is currently altering the nature of natural land cover though direct actions such as urbanization, industrialization, and deforestation, through indirect actions such as ranchland overgrazing which can lead to desertification of the land, and disposal of waste materials. Studies have demonstrated that the scales reach of human activity is clearly sufficient to alter the land environment on regional scales. It is only a matter of time before these scales reach continental and, eventually, global proportions. These changes have not been qualified, do not have the ability of natural systems to adjust to the changes or recover from past changes, and have not been studied sufficiently to allow useful projections of future habitability of the plane.

In land cover dynamics research, three specific research areas have been identified: (1) The extents and rates of deforestration (2) desertification; and (3) urbanization. The Space Station could provide the opportunity to fly both low and high resolution, multi-spectral instruments to provide data for both survey and detailed studies. An appropriately instrumented Space Station could also obtain global data for extended periods of time from which secular and seasonal changes could be separated from long-term changes in the land cover. Additionally, atmospheric and hydrologic data could be acquired from the complement of instruments on the Space Station supporting other disciplines to indicate impact of land cover changes on those physical systems.

Hydrologic Cycle Research And Monitoring. Because of its impact on the vegetative and atmospheric physical systems, a basic requirement exists to develop knowledge and understanding of the Earth's hydrologic system, particularly the hydrologic cycle. For example, soil moisture is a crucial parameter affecting agricultural production and energy balance of the Earth's surface. A given soil moisture value results from the interaction of precipitation, evaporation, and runoff processes. Evaporation affects weather and climate predictions. Evaporation also provides the moisture resource in the atmosphere for precipitation to occur, thus closing the cycle.

The world's water resources available for personal, agricultural, and industrial/commercial use reside in underground aquifiers, reservoirs, lakes, and rivers that are replenished directly through precipitation and indirectly through snowmelt runoff in high latitude areas. Uncertainty exists in regional and even sub-continental estimates of the supply of water that is or will be available for man's use because of uncertainty in areal extent and condition (such as pollution) of water equivalency of snow cover. It is important to study these parameters and make continuous estimates of their numerical values and trends for both research and resource management purposes. For example, sediment or pollution conditions can damage the quality of water to such an extent that it is unfit for consumption or industrial/commercial use. Snow water equivalency values are used in snowmelt runoff models, predictions of which are used for water management. Because of its bright albedo, snow also affects the Earth's energy balance since it covers a significant fraction of the land mass in winter, which in turn influences weather and climate forecasts and predictions.

3.1.3.2.7 Geosciences. Monitoring the Earth's resources from space is far more economical and practical than using conventional methods such as airplanes and ground surveys. Although many of the details of determining the characteristic signatures of rock units are still being developed, several advantages of space-borne resource monitoring are already apparent. Wide coverage over short periods of time, short revisit cycles, examination of inaccessible areas, and flexible instrument designs are some of the most important advantages.

A number of rapid and potentially dangerous phenomena may also be studied by remote sensing methods. These include volcanism, landslides, rapid tectonic deformations, or crustal dynamics. This area, in particular, is exciting because of the wealth of information available today. A Space Station could play a significant role in refining our concept of global rock distribution and geologic structures and in detecting or monitoring geodetic changes.

Geology (ESR). The goal of geology is to acquire sufficient information on composition, structure, and chronology to reconstruct the geological evolution of an area. Remote sensing is particularly useful for determining structure and lithology. With the advent of a Space Station in the early 1990s, use of visible and infared imagery obtained by Landsat to discriminate and identify rock units and map surface structure will have been learned. Significant advancements in radar remote sensing will have been made toward understanding the effect of variable incidence angles, wavelengths, and polarizations on the interpretability of orbital radar imagery. The next step will be to combine these two types of data in a controlled manner (registered and calibrated) to determine what geological information can be obtained from the combined data sets. In order to pursue these studies, the diverse data sets must be acquired simultaneously or near-simultaneously since data acquired at different times depend upon additional variables such as surface temperature, soil moisture, and vegetative cover, thus making comparisons extremely difficult. The advantage offered by the Space Station is its capability of supporting many large instruments so that data may be acquired over a particular area simultaneously.

Various types of geological information can be obtained through the analysis of remotely sensed data. In areas where geological materials are exposed at the Earth's surface, information concerning the minerology, chemical composition, and physical structure of certain rocks and soils can be directly inferred. The general term, lithology, refers to these gross characteristics of rock materials. In areas where natural vegetation obscures underlying geological materials, remotely sensed data can provide information about the areal density of the vegetation, the occurrence and distribution of specific species, and the health or vigor of selected species. Under certain circumstances, this information can be used to infer something about local geological conditions. The use of botanical variations to detect lithologic boundaries between different types of rocks and soils is generally referred to as geobotanical mapping.

Crustal Dynamics (ESR, GRM). Measurements of crustal deformations can provide information on stresses within the Earth, the interior rheology, and subsurface structure. Within the context of tectonic plate theory, they provide information on the driving mechanism for plate motions and assessing plate rigidity. On a regional scale, geodetic measurements can provide information on the accumulations of strain in seismically-active regions. Geodetic measurements provide information on spatial and temporal patterns ranging from several months to decades. Crustal deformation can be interpreted in terms of tectonic plate motion, strain accumulation and release, and other horizontal and vertical motions. This study will provide data needed for fundamental theoretical and computational studies of both earthquakes and other processes that deform the Earth's surface which are necessary to provide a framework for interpreting geodetic measurements and for modeling the underlying physical processes.

The Space-Borne Laser Ranging System consists of a pulsed laser distance measurement system that sequentially measures the distance to a number of retroreflector arrays on the ground. From orbit, the laser measures the range to the corner reflectors on the Earth's surface as it passes overhead. The measurements can be stored on the Station and, subsequently, relayed to a ground terminal. The measurement objective of the system is a relative position uncertainty in the locations of the reflectors of 1 centimeter (cm) precision or better for separations of reflectors on the order of several thousand kilometers.

3.1.3.2.8 Detection/Monitoring/Assessment Of Episodic Events (ESR). Disaster management encompasses a number of man-induced and natural disasters including floods, landslides, earthquakes, volcanic eruption, insect and disease infestation, drought, forest/range fires, and oceanic oil spills. Activities include the initial detection and identification of the event, short- and long-term monitoring of the event and its consequences, environmental impact assessment, and baseline research studies in support of the disaster. The activity phases for any particular event involve differing sensor needs (i.e., spectral bands, spatial resolution) and varying platform requirements (frequency of observation, aerial coverage, stereo capability).

Satellites perform a complementary role to field surveys, aircraft reconnaissance, and ground data collection in obtaining information regarding a disaster region, since it is frequently characterized by inaccessibility and/or poor visibility due to clouds, haze, and smoke. In many cases, satellite imagery is the only information available for quantitative assessment. While most satellite systems currently in existence are not suitable for disaster management applications, the tremendous toll that they extract makes it imperative that Space Station utilization include sensors optimized for the observation of man-induced and natural disasters.

While a geostationary platform would provide continuous coverage of a portion of the Earth and day/night capability, limitations of technology related to low spatial resolution, large view angles, and engineering complications minimize the feasibility of this platform. On the other hand, a near-polar platform in low-Earth orbit would provide stereo coverage of the entire Earth with a lower frequency of observation. Observations, decisions, modifications, and interactions between persons, instruments, and teams that are required for the study of episodic events would benefit from the capabilities of a man in orbit.

3.1.3.3 Solar System

In the 1990s, planetary observations with sophisticated instruments from Earth or from Earth orbit will greatly enhance the understanding of planetary science. However, even the most advanced sensors cannot perform in-situ measurements of planetary atmospheres, magnetic fields, charged particle environments, nor high resolution observation of the distant planets. Consequently, a solar system mission will remain a significant part of the Earth and planetary exploration program well into the next century.

A Space Station in low-Earth orbit offers potential advantages in the assembly, checkout, and launching of these missions. As viewed in this operational role, upper stage propulsion systems could be fueled at the station depot and mated to the spacecraft payload prior to launch. Automated planetary missions, particularly those requiring large mass spacecraft systems, might well benefit from this on-orbit staging. The key factor in this case is the ability to fully load propellant in the upper stage unconstrained by Shuttle cargo weight limitations.

Since planetary mission launches must occur during specified launch windows, staging from a Space Station may present performance penalties. The major source of performance penalty is that on the optimal launch date, the Station's orbit plane will most likely not be aligned with the required 4d Earth-escape trajectory plane. Since it is not reasonable to expect the Station orbit would be preset or modified in advance to satisfy planetary mission requirements, an appropriate injection strategy must be employed to minimize the performance penalty. An analysis of a range of possible injection strategies indicates that it is most efficient to adopt a passive "launch date timing" strategy which relies on the natural precession of the Station's orbit plane caused by Earth oblateness. Plane change maneuvers are reserved only for fine tuning purposes.

Several different types of support functions need to be performed at a Space Station serving as an operations base for staging planetary missions. The six functional categories identified are: (1) storage; (2) assembly; (3) servicing; (4) checkout; (5) deployment; and (6) recovery.

The core solar system exploration program consists of the following missions and launch dates.

Mission	Launch Date
Mars Geosciences/Climatology Orbiter	1991
Comet Rendezous	1991
Lunar Geosciences Orbiter	1991
Titan Flyby/Probe	1993
Saturn Flyby/Probe	1994
Venus Atmospheric Probe	1994
Multiple Main Belt Asteriod Orbiter/Flyby (2 launches)	1997
Saturn Orbiter	1998
Near-Earth Asteroid Rendezous	1999

This basic mission set can be implemented with the Shuttle/Upper Stages either currently available (IUS, PAM, SRM-1) or under development (Centaur). Consequently, no enabling technology is required. However, all of these missions could be captured with an OTV staged from a Space Station but a Space Station/OTV implementation mode may neither be the most efficient nor least costly mode.

Additionally, other high priority solar system missions that require development of enabling technology are under consideration. A Mars Sample Return Mission (1999 launch) is an example of a mission which can be implemented only with on-orbit assembly, potentially at the Space Station.

3.1.3.4 Life Sciences

Clearly, gravity plays a key role in much of biology. Plants grow upward partly in response to gravity. Animals develop circulatory systems to distribute nutrients and skeletal systems for support in Earth's gravitational field. Preliminary data indicate that even the embryonic development of higher animals may be heavily influenced by gravity. Though certain physiological changes and some gravity-dependent phenomena can be studied during the relatively short Shuttle missions, others such as adaptation of microgravity) simply require longer exposure to the space environment. The availability of a Space Station provides an unparalleled opportunity to study the effects of gravity and weightlessness in several species of plants and animals including, of course, humans.

A compelling question that bridges the gap between fundamental studies in gravitational biology and operational aspects of space medicine is: "Can man remain healthy in a weightless environment for months to years?" A number of biomedical problems affecting a variety of organ systems have been encountered during space flight. These include bone demineralization, cardiovascular deconditioning, atrophy of gravitational support muscles, and changes in blood constituents. We do not know whether these problems stabilize, recover, or acquire medical significance following several months exposure to zero-g. In other words, the term "healthy and normal" needs to be defined for the space traveler. These are among the most important research issues currently facing the space life sciences community.

The solution to these problems will require a dual approach in the Space Station era. First, clinical studies performed by medical personnel are needed to characterize and establish a baseline of physiological norms for long durations in zero-g. These studies would suggest procedures for the appropriate health assessment of spaceflight personnel and the application of countermeasures where necessary. Second, carefully controlled longitudinal studies, whereby both human and animal subjects are monitored for several months, are needed by researchers in gravitational biology and physiology to unravel the total human physiological response to zero-g and to determine the underlying mechanisms of each component part of that response.

Operational support studies require Space Station facilities that are parallel to those required to support basic research. In some cases, particularly when the studies involve human subjects, such facilities are identical. The major life sciences functions consist of basic health care, human biomedical research, gravitational biology research, and regenerable life support systems research.

3.1.3.4.1 Basic Health Care (Health Maintenance Facility). The consideration of health maintenance will influence any Space Station concept because of its contribution to sustaining the life and well being of the crew. A Space Station will bring NASA into a new area when "individual activities," long stay times, frequent extravehicular activity, and scientific and flight test activities will be commonplace. The varied activities of a diverse Space Station crew will increase the potential for industrial accidents such as trauma, burns, infections, and psychological problems. Any of these may complicate the physiologic changes already associated with micro-gravity. Infectious diseases will also be of concern in the closed environment of a Space Station, and methods to diagnose, treat, and possibly quarantine individuals must be developed. If a crewmember becomes critically ill, that person cannot return to Earth but must be treated and cared for in the Space Station facility -- and that care will place demands on the rest of the crew.

Several types of physiological deconditioning in weightlessness have been identified. For this reason, health care must involve not only the diagnosis and treatment of accidents and diseases, but also the prevention of chronic problems and the maintenance of a healthy state. Thus, the health care program must include a physiological/psychological monitoring system, a crew health data base for tracking routine exams, recommendations for individual exercise, diet, and rest/work schedules, the monitoring of environmental parameters, the assessment of human performance, and the development of standards for habitability factors.

Health maintenance facilities will be developed in several stages, beginning with the already proven Shuttle Orbiter Medical System (a sophisticated first-aid kit) augmented to provide emergency care. As the number of individuals, lengths of stay, and size of the Space Station increase, the area dedicated to health care and maintenance will expand to include a first-aid station, an exercise area, the diagnostic and treatment facilities of a physician's office, and eventually the equivalent of a two-bed hospital. With some modification, these facilities can be used to accommodate clinical studies that support human biomedical research and health care issues.

3.1.3.4.2 Biomedical Research (Health Maintenance Facility, Human Laboratory, Annual Lab Vivarium). During previous space flights, man has experienced physiological changes that may have detrimental consequences over the long-term. Significant findings include loss of skeletal mass and calcium, decreased red cell mass, increased numbers of abnormally shaped red blood cells, decreased plasma volume, increased numbers of white blood cells, changes in hormone concentrations in the blood, redistribution of body fluids, deconditioning of the cardiovascular system, loss of muscle mass and nitrogen stores, and vestibular changes leading to space sickness. Most of these events appear to be normal adaptations to zero-g but without intervention, they may endanger the health and safety of crews during longer duration space missions.

Studies that employ a wide range of human and animal subjects must be conducted to characterize these problems, determine their underlying mechanisms, assess the longer-term effects, and suggest countermeasures and/or solutions. Several foreseeable problems in long-term habitation in space include increased propensity for bone fractures and anemia, impaired immune response, orthostatic intolerance, and complications resulting from space sickness. In addition to these known biomedical problem areas, other potential problem areas have been identified and need careful assessment. These include investigations of micro-gravity effects on basic metabolic activity (e.g., glucose metabolism), gastrointestinal function, central nervous system activity, biorhythms, the aging process, the development of chronic degenerative diseases, and the neurophysiology and vestibular system control. Long-term radiation effects must also be assessed.

Medical care in micro-gravity calls for different standards and requirements than those employed on Earth. Before researchers can determine which physiological changes occurring in zero-g are abnormal, they must first know the normal range of zero-g physiological behavior. At present, there is no adequate characterization of in-flight trauma to bone and skin tissues that are most susceptible to injury during space flight. Bleeding problems. clotting, inflammation reactions, and healing rates need to be examined, characterized, and analyzed to determine their appropriate treatment in space. The effectiveness of drugs in disease therapy must also be reassessed because micro-gravity effects have the potential to alter certain aspects of pharmacokinetics (such as gut absorption, distribution in body fluids, and excretion). Finally, the development of techniques and instrumentation necessary for a major surgical facility (e.g., surgical tools, containment of bleeding, anaesthesia, and fluid handling) should proceed, even though such a facility may not be cost-effective during the early stages of a Space Station.

The totality of requirements associated with human biomedical research encompass a range of activities from the development of practical hands-on medical procedures to the conduct of fundamental academic studies. Basic human microgravity adaptation studies and medical operations development will eventually require separate facilities -- a human research facility for physiological research, a health maintenance facility for medical operations studies, and an animal vivarium and lab. Clinical research and treatment needs can be met by sharing the laboratories ans staffs of both facilities. There may be some overlap, but not necessarily redundancy, in the facility requirements.

3.1.3.4.3 Gravitational Biology Research (Plant And Animal Vivarium And Lab Centrifuge). Gravitational biology (also called space biology) is the study of life in the space environment. Its scope includes all thos disciplines from microbiology to ecosystem dynamics contained within the scope of the biological sciences on Earth. All life that we know has been shaped by the environment of Earth; an environment that contains naturally occuring liquid water, a constant energy source (the sun), constant gravity, stable magnetic fields, effective radiation shielding, an appropriate atmosphere, and an ecosystem that continually recycles nutrients and waste products through physical, chemical, and biological processes. To support life in space, each desirable element of the Earth's environment must be deliberately engineered into a spacecraft's design. From an applications perspective, the requirements of the organisms that will live in space must be known and met. These requirements are delineated through basic research of the processes by which life responds and adapts to the space environment.

Microgravity is the one factor that cannot be adequately simulated on Earth. Gravity is believed or known to influence life from fertilization through birth, maturation, and death; how that influence is physiologically manifested remains highly speculative. To address these issues, a variety of plant and animal species must be flown in space.

One of the major problems identified for future study in space concerns animal development. Some issues in this area concern the effect of gravity on tissues whose function of Earth is skeletal support or circulation of blood and fluids against gravity. The mechanisms by which higher organisms discern direction and orient themselves in a one-g field develop soon after conception. It is not known if gravity is necessary to the embryonic development of those mechanisms. On Earth, phenomena such as the parental rotation of bird eggs, and self-generated rotation of development of frog eggs soon after fertilization, and the orientation of embryos in the rat uterus, support the notion that gravity is a significant factor in the production of viable offspring. Among the other major problems requiring future study in gravitational biology are those that concern the influences of gravity on reproduction, biorhythms, plant biology, and radiation biology.

Non-human species will be employed in gravitational biology research and as supplementary test subjects in both biomedical (animals) and life support systems (plants) studies. Animals have been used for biomedical research throughout the ages because they offer crucial aspects of experimentation that are not possible on human subjects. Just as animal experiments lead the way to life saving medical advances on Earth, every step of man's journey into space must be preceded by animal experiments to acquire data to protect the astronauts now and in the future. Animal experimentation can significantly increase our understanding of zero-g physiological responses in many areas, including: bone demineralization, muscle loss, fluid/electrolytes, metabolism, neurosensory physiology/function, and cardiovascular deconditioning.

To carry out research using animals and plants to study the physiological effects of zero-g and the general role of gravity on living systems, a vivaria (or habitats) for the specimens are required (Man-Tended Life Sciences Research Facility, Marshall Space Flight Center; January, 1982). The vivaria must provide air, water, food, and waste treatment to keep the animals and plants healthy and stable. It is projected that plants ranging in size from algae to leafy vegetables) and animals (ranging in size from mice to large primates) will need to be accommodated. The vivaria must also contain facilities to support "active" experiment requirements such as tissue analysis, microscopic examinations, chemical preparation and storage, surgery, and dissection. Some experiments will be "passive" and simply require that specimens be maintained in the vivaria for long periods of time prior to study.

To determine gravity effects on genetics, reproduction, embryological development, maturation, and population dynamcis, many generations of space-born plant and animal species must be studied. It will also be desirable to study the combined effects of micro-gravity and other stresses such as exercise, light cycles, heat, radiation, and diet on these organisms. In addition, a centrifuge facility is needed to provide a one-g control for the zero-g experiments and to study graded responses between zero-g and one-g. The centrifuge area would represent a one-g holding facility in which a limited number of plants and animals could remain until needed for zero-g experimentation.

3.1.3.4.4 Life Support Systems Research (CELSS Experiment Facility, Pallet, And Module). The first Space Station life support system will use substantially more consumable supplies than would be necessary with a fully developed regenerative system. As the Space Station's size and operational scope increase, the life support system will need to be enhanced, not only to expand operating capacity, but also to decrease dependency on consumables (such as food, water, and oxygen).

In particular, subsystems that are dependent on the behavior of free liquid surfaces would be candidates for in-flight testing. For example, some major studies will use 60 to 100 gallon algae and yeast growth chambers to recycle oxygen and metabolic wastes. These chambers must deliver the appropriate liquids and gases to the organisms in a usable form. However, gases that are simply bubbled through the chambers in zero-g will not be in a form that is usable to the organism so some other technique for their delivery must be devised.

The Controlled Environment Life Support System (CELSS) studies synthesize elements from most life sciences research programs to develop a regenerative life support system that can support human crews indefinitively in space using no external input except light energy. The CELSS program is aimed beyond the Space Station to provide life support to crews conducting planetary, far Earth orbital, and other long-duration missions in which it is impractical to resupply food, water, oxygen, and other vital materials.

Three phases of CELSS-related experiment activities are envisioned. The first phase will last for three to five years and will characterize the performance requirements of and determine criteria for the successful management of biological systems in weightlessness. During the first phase, CELSS will share facilities and results with the advanced life support and gravitational plant research programs to determine the fundamentals of biological processes and their adaptations to weightlessness. The second phase, also lasting between three and five years, will verify that the processes chosen for development from phase one can be scaled up to the size required for real systems. Preliminary models of CELSS subsystems will be used in this phase. The third phase will take about three years and will consist of operational tests on a complete prototype system supporting human occupants.

Typical major experiments in the first phase include:

- Characterizing plant root growth in weightlessness, defining the minimum amount of water needed for normal development, and determining the chemical products that the waste management system must supply to the plants;
- Determining the processes by which large scale (60-100 gallons) algae and yeast growth chambers can be maintained; and
- Assessing the usefulness of anaerobic and aerobic microbes for digestion of human and other food chain wastes.

During the second phase, a large-scale, plant growth experiment is planned in which each growth system studied will be large enough to feed two people. Each crop will be grown within $6m^2$. Measurements will be made in-flight to determine plant nutrient pathways and rates of carbon, oxygen, and water transfer into and out of the system. Instrumentation will be adapted from analyzers used in ground-based laboratories. These tests will require separate facilities.

In the third phase, a major experiment will be to validate the chosen system integrated from subsystems previously tested in-flight. It is envisioned that two people will occupy one Space Station module for a specified period of time, completely supported by the life support system, to verify its habitability. This validation test may require a relatively long period of operation to ensure sufficient time for the recycling of materials within the life support system. If higher plants are used, this test may last more than a year.

3.1.3.5 Materials Processing In Space

Most materials are prepared from liquids or gases under conditions that allow gravity to cause uncontrolled fluid motions. The Materials Processing in Space (MPS) program provides a unique set of capabilities and opportunities to study such effects and develop methods to achieve enhanced control over the processing variables. Ultimately, a deeper understanding of materials processing should permit the development of innovative processing technology that will be adaptive to the forms of energy that are available and to environmental constraints and that will be attractive from the viewpoint of cost. NASA's research on materials processes, therefore, involves multi-disciplinary contributions that will result in an effective basis for the utilization of new environments such as that of space. The NASA MPS program is also encouraging commercial applications of materials processing/technology through involvement of the private sector with Joint Endeavor Agreements (JEAs). These enhance the transfer and adoption of new processes for public use and encourage close collaboration between the scientific communities in government, universities, and industry.

A major concern to the MPS program is the length of time needed to conduct a flight experiment. It takes from five to seven years from the proposal of an MPS investigation to its first flight on the Shuttle. Even then, a scientist will have access to the orbital, micro-g environment of the Shuttle for no more than approximately 1 day in 10 because of the short (7 day) mission time and the long (70 days) refurbishment time at Cape Canaveral. The average length of time spent by a materials scientist on Earth to complete a research program is about 3 years. In order for the MPS program to have a significant impact on research on ground-based processing technology (and lead to the manufacturing of novel, high technology materials in space), the length of time needed to obtain a complete set of flight results must be shortened significantly until it is at least comparable to that spent on ground studies. A manned Space Station, which can be used as a continuously operating micro-g laboratory, should help to significantly reduce time and thereby allow the results of flight experiments to have an impact on ongoing programs studying the processing of high technology materials.

The program currently consists of four major processing areas: (1) crystal growth and solidifications; (2) containerless processing; (3) fluid and chemical processing; and (4) bioprocessing. In all four areas, the availability of man in space is essential to all stages of the experiments (pre-experiment characterization, experiment initialization, monitoring, result characterization, decision-making [perhaps in collaboration with scientists on the ground], and set up for the next experiment).

3.1.3.5.1 <u>Crystal Growth And Solidification Processes (Laboratory)</u>. This research discipline encompasses those experiments where materials are solidified in a controlled manner from the melt, from vapor, or from an aqueous solution. The crystals are generally of semiconducting materials such as germanium (Ge) and Indium (InSb), but several different types of alloys have also been studied. Furnaces of various types are usually utilized, but other types of apparatus include a solution crystal growth system.

The detailed requirements for the experiments will vary greatly depending on the type of growth. One would like to configure the Space Station to function in the same manner as a ground-based laboratory. Therefore, some pre- and post-experiment characterization of the samples should be done in space. The capabilities for slicing, polishing, etching, and surface analyzing should be available on a Station, while detailed characterization and analysis can be done using more sophisticated techniques and experts on the ground.

3.1.3.5.2 <u>Containerless Processing (Laboratory)</u>. This research discipline investigates the processing of material (i.e., the heating, melting, superheating, cooling, and solidifying) without touching a container. This should significantly reduce contamination and heterogenous nucleation which are largely container-induced. Specific research areas that currently utilize containerless processing include the measurement of the thermosphysical properties of materials at high temperatures and the production of amorphorous materials. Since this is a novel research discipline, the MPS program not only supports the basic research studies but also is developing the containerless technology using such systems as acoustic, electrostatic, electromagnetic, and aerojet.

Measurements of the properties of the materials can be telemetered to the ground; however, at least preliminary analysis of the composition and structure of the specimens should be performed interactively on the Space Station.

3.1.3.5.3 <u>Fluid And Chemical Processes (Laboratory)</u>. This area of research studies the behavior of fluids and fluid-related processes to better understand the influence of gravity and gravity-dominated behavior on ground-based processes. This information will be used to develop methods of enhanced control over the processing variables in gound-based systems. Specific research areas include studies in the microphysics of cloud formation and combustion science. Research also includes the study of fluid behavior in a micro-gravity environment as general support for the other research disciplines of the MPS program.

Since the bulk of the experiments examine fluid and transport behavior in micro-gravity, the data can be telemetered down for use of the principle investigators on the ground. The data could consist of visual observations, mass spectrometry, and temperature variations. Some investigations may result in a product, such as monodispersed latex beads which would be partially characterized in orbit.

Within the Space Station, long-duration, controlled, low-gravity levels can be achieved that will allow the successful conduct of numerous experiments in fundamental combustion science. For example, long durations will allow experimentation on non-flaming phenomena such as smoldering. Also, discrete gravity levels could be available that will provide a test bed for examining flammability limits. The key feature that a Space Station could provide is the long-duration, controlled, low-gravity levels in a manned laboratory environment. In fact, astronaut involvement will provide the necessary space, power, and thermal control. This laboratory should contain the basic support services for the conduct of a broad range of combustion science experiments.

3.1.3.5.4 Biological Processing (Laboratory). This research discipline involves the separation of biomaterials (e.g., proteins and viable cells) using techniques (e.g., isoelectric focusing) that utilize intrinsic properties (zeta potential) of the material. This discipline also includes measurement of physical properties of biomaterial in orbit to obtain data that are difficult to obtain on the ground. Such an investigation might include the measurement of the viscosity of hemocrit at low flow rates.

Some of the experiments will study basic scientific phenomena and the data can generally be telemetered to investigators on the ground. However, many of the studies will produce separated/purified material. As in the other disciplines, a preliminary assay of the materials should be made in orbit. In the case of the separation of viable cells, this may involve cell culturing systems as well as product characterization tests.

3.1.3.6 Communications

This area of research deals with the development of new high-risk technology and applications for communications satellites. One of the program goals is to test the feasibility of a geosynchronous platform for large antennas and multiple users. The experimental geosynchronous platform would incorporate a bus to provide power, attitude control, and housekeeping data control subsystems as well as the servicing/resupply interface. The platform booms and antennas would be deployed, aligned, and tested at the Space Station, be mated to an OTV, and transferred to geosynchronous orbit. Geosynchronous servicing (resupply) from the Space Station could then be demonstrated using the OTV and the experimental, geosynchronous platform.

3.1.4 The Mission Model

The mission model for space sciences and applications is shown in Table 3-2. The model includes on-board accommodations for life sciences, intensive man-interactive investigations (e.g., materials processing), and other activities (e.g., cosmic ray physics). The model may contain platforms associated with the manned element as needed to accommodate "contamination" (jitter, particulate, and EMI) and special orbit requirements.

Servicing and construction is supplied by the Space Station in the model for free-flying missions launched prior to the Space Station and co-orbiting platforms (from the Station), and other platforms and free-flyers (from the Shuttle if not the Space Station.) Finally, in the model the Space Station is a transportation mode for geosynchronous satellites and solar system missions.

TABLE 3-2

SPACE SCIENCE AND APPLICATIONS
Summary Element*

TIME PERIOD	PRESSURIZED LABORATORY	ATTACHED PAYLOADS	FREE FLYERS	TRANSPORTATION NODE
1991-1992	MPS R&D FAC. HEALTH MAINT./CL. RES. AN. & PL. RES. L./VIV. HUMAN RES. LAB. CELSS EXP. SYS.	SCRN SP. PL. PHYS/M SOT* LIDAR FAC.*	E. SCI. RES. (ESR-1) SP. TELESCOPE GRO OPEN XTE GRM TOPEX SMM	MGCO LUN. GEOC. ORB. SDO COMET REND.
1993-1995	PILOT BIO. PROC. FAC. PILOT C'LS. PROC. FAC. PILOT FUR. PROC. FAC.	CELSS PALLET SIRTF* STARLAB*	AXAF OVLBI FUSE	VENUS ATM. PROBE TITAN PROBE EXP. GEO. PLAT.
1996-1998		HTM HI. E. ISO. EXP. PIN H/OCC FAC.* TRIC	LDR SIRTF (SS)	GOES F/O MAIN B. AST. REND. SATURN ORB.
1998-2000	DED. CELSS MODULE	SCDM* ASO*		N. E. AST. REND. MARS SAMP. RET.

* SPECIAL POINTING AND CONTAMINATION REQUIREMENTS

These several types of services by the Space Station have been phased in our model according to the advanced plans of OSSA. However, three types of new activities are either demanded or enabled by the existence of the Space Station. There are: (1) Long-duration life science missions; (2) materials processing experiments; and (3) planetary sample return. These three deserve some special mention relative to the rationale for their time-phasing.

The physiological changes that occur in man in long-duration stays have been listed from previous flights and for ground-based simulation. However, they are not known quantitatively. To even plan for optimum manning of the Station in the latter stages of the 20-year time, a concerted effort (with humans and animals) is needed immediately in the mission. Thus, these facilities (the health maintenance, laboratory, and vivarium facilities) appear at the beginning of the model.

In materials processing, the Station will potentially initiate a new industry. Thus, the research lab was placed early in the model so that the pilot demonstration and actual commercialization may be possible at the earliest feasible time.

The return of a sample from a planet requires immense propulsion capability -- far in excess of the STS launch weight for a single launch. The Station (as a transportation node) enables such a mission. This mission has been placed late in the model based on the SSEC recommendations and to allow adequate preparation time for such a complex mission.

The remainder of the missions have been placed in the model at rates at which realistic (but optimistic) budget projections can support them. The order of their appearance within an area (e.g., astrophysics) is according to their "science priority," (i.e., the best advice of the committees). The science and application mission modes are as follows.

Requirements On-board Or In Close Association With The Space Station

- Initial Phase Space Station
  - Health maintenance facility (in baseline Station)
  - Human research facility
  - Vivarium and geological research facilities
  - CELSS experiments capability
  - Materials processing experiment facility
  - Accommodate payloads with Spacelab heritage
    - Starlab
    - Solar Optical Telescope
    - Lidar Facility
    - Synthetic Aperture Radar
    - High Resolution Via/IR Imagers
    - Space Plasma Lab Experiments
  - Provide co-orbiting platform of any of the above which cannot be proven to be capable of accommodation on Space Station
- Intermediate Phase
  - Materials processing factories -- on-board or co-orbiting
  - Accommodate permanent observatories
    - Shuttle Infrared Telescope Facility
    - High Throughput Mission
- Full Capability Station
  - Construct large payloads on-orbit
  - CELSS module (2-man)

Servicing Of Co-orbiting Payloads And Platforms

- Initial Phase Space Station
  - Service co-orbiting payload
    - Space Telescope
    - Solar Maximum Mission
    - Gamma Ray Observatory
    - X-Ray Timing Explorer

- Service co-orbiting platform for experiments not accommodated on Space Station itself

- Later Phases

  - Expanded service for advanced X-ray astrophysics facility and other new satellites

  - Deployment and servicing of LDR

Operations And Servicing In Non-Space Station Orbits

- Initial Phase

  - Provide and service (via STS) a near-polar platform

- Intermediate Phase

  - Assemble, launch, and service geostationary resources

    -- Large communications satellites
    -- Earth observing platforms

  - Launch of comet and Mars sample return missions

- Complete capability Space Station

  - Sample return laboratory

  - Additional manned elements if necessary in other orbits

  - Construction of facilities for launch to other orbits

3.1.4.1 Space Station Capability Analysis

The Advocacy Group did a crude analysis of the capability of the Space Station to enable or capture missions.

3.1.4.1.1 Enabled Missions. A number of science and application missions are enabled by the Space Station. A materials processing, R&D facility and pilot plant facilities for biological, containerless, and furnace processing require longer, man-tended durations than are available on the Shuttle to demonstrate the vaibility of materials space processing for commercial use. The life sciences program consisting of a health maintenance and clinical research facility, a human research laboratory, an animal and plant vivarium and laboratory, a controlled environment life support system (CELSS) experimental systems, a CELSS pallet, and a dedicated CELSS module also require long-duration, man-tended missions. The LIDAR facility will require frequent servicing and configuration changes for evolutionary development combined with an extended mission duration to be economically feasible. The Mars sample return mission required on-orbit assembly of the payload and escape stage. Capture of the return stage and some analysis could also be performed utilizing the Space Station system. The experimental geosynchronous platform is enabled in the sense that Space Station deployment and alignment will allow larger antennas than could be packaged in the Shuttle bay.

3.1.4.1.2 Capture Analysis. The existing science and applications program was analyzed to determine the missions that could be flown using the Space Station manned element and/or associated platforms. The following missions can be flown attached to the Space Station: (1) Spectra of cosmic ray nuclei; (2) space plasma physics payload; (3) transition radiation and ionization calorimeter; (4) the high throughout mission; and (5) the high energy isotope experiment. If the rigorous pointing and contamination requirements can be met, the solar optical telescope, LIDAR facility, Shuttle infrared telescope facility, Starlab, the pinhole/occultation facility, the solar corona diagnostics mission, and the advanced solar observatory can also be flown attached. If the requirements cannot be met, then these missions can be flown on a co-orbiting platform to provide accessibility.

Due to orbital constraints, a number of missions in the current science and applications mission set will be flown as free-flyers even if the Space Station is in place. Many of these free-flyers will be designed for on-orbit servicing and could be serviced by the Space Station using either the TMS or the OTV in place of the Shuttle. The missions that could be serviced by the TMS are: (1) The space telescope; (2) the gamma-ray observatory; (3) the X-ray timing explorer; (4) the solar maximum mission; (5) the advanced X-ray astrophysics facility; (6) the far ultraviolet spectroscopy experiment; and (7) the large deployable reflector. In some cases, only scheduled maintenance can be performed due to differential nodal regression rates. The other free-flyers identified require orbital inclinations between 57 and 99 degrees. It may be more economical to service these missions from the Shuttle than from the Space Station and the OTV.

All of the missions shown using the Space Station as a transportation mode (except the Mars sample return and experimental geosynchronous platform) can also be performed with the Shuttle and an existing upper stage or one currently being developed. The selection of the Space Station/OTV or Shuttle/upper stage as the launch vehicle for these missions will depend on cost, Shuttle scheduling, and OTV initial operational capability (IOC) date.

There is a special capability that could be provided by the Space Station that might be useful but has not been given careful consideration; it is "shirt-sleeve" work on an attached instrument. Mounting an instrument in an airlock-like pod is worthy of more attention.

3.1.4.1.3 Contamination Requirements. There are some special requirements in science and applications levied on pointing and chemical contamination. While all of the sensors (outward-directed or Earth-directed) have some such requirements, they are the most stringent in astrophysics. To demonstrate the pointing and contamination requirements, they are presented below for a representative set of instruments consisting of the solar optical telescope, the Shuttle infared telescope facility, Starlab, the pinhole/occulter facility, the solar corona diagnostic mission, and the advanced solar observatory.

- Contamination
  - Sensitive to 10^{15} molecules/cm^2
    - Deposit less than 10^{12} molecules/cm^2/yr. on optical surfaces
    - Less than 10^{13} molecules/cm^2 along line of sight during operations
    - SIRTF requirements are 3 orders of magnitude stricter than above
  - SOT, Starlab, SCOM, and ASO are sensitive to hydrocarbons
  - SIRTF is sensitive to H_2O and CO_2 as well

- Above estimates are preliminary and may become more severe as on-orbit data are acquired

- Pointing Stability
  - 0.1 arc-sec stability required
  - SOT and SIRTF require image motion compensation to operate on STS
  - High frequency (1 HZ) disturbances to IPS cannot exceed 0.1 arc second

- Pointing Accuracy and Knowledge
  - Accuracy is mission peculiar, ranging between 0.1 and 60 arc seconds
  - All require 0.1 arc-sec knowledge

3.2 COMMERCIAL

3.2.1 Introduction

The object of this section is to synthesize an integrated mission set of potentially viable commercial opportunities for implementation on a Space Station. Commercial opportunities in space are those products, processes, and services that demonstrate technical, economic, and institutional viability sufficient to achieve private sector investment in, ownership of, and operation of the activity as a profit-making venture. Commercialization of activities in space is based on an evolutionary process of concept identification, commercial assessment of the feasibility of the concept, enabling technology definition, technology development, experimentation, system design, system test and validation, and reassessment of commercial viability. This process assumes that the Space Station is an enabling technology that provides facilities, utilities, and amenities to encourage the private sector to experiment and develop new products, processes, and services in space.

It is also assumed that the government participates in and supports this evolutionary process through continuing basic science research programs, technology development and demonstration programs, and by simplifying the technical and institutional requirements to utilize space.

The commercial opportunities are described in four categories representing materials processing, earth and ocean observations, communications, and industrial services.

Materials processing may be the first profitable, commercial venture to utilize a Space Station. High value, low mass items, particularly of use in national health or in defense-related materials, show promise of large, stable markets that may justify early investment.

The commercial potential of earth and ocean observation systems has been vigorously debated over the past decade in areas such as agriculture, land management, oceans, arctic operations, and geological and mineral exploration. Some commercial potential does exist for Space Station earth and ocean observations, but numerous institutional and market problems remain to be solved. Further, these missions typically have strong requirements on orbit selection and may even demand a capability to occasionally change orbits to be most profitable.

Communications has been the major successful space commercialization activity. Private communications companies may benefit from Space Station capabilities to service satellites, repair elements, or assemble and calibrate large antennas or platforms. Orbital Transfer Vehicle (OTV) operations and geosynchronous satellite launch and, eventually, retrieval and repair will also provide capabilities useful to the commercial communications industry.

Commercial opportunities in industrial services may include operation of a space-based Orbital Transfer Vehicle (OTV), a Teleoperator Maneuvering System (TMS), leasing a satellite bus or platforms, servicing satellites, orbital and ground base data services, specially trained commercial crews, and integration and ground check-out services.

Many Space Station advocates have the opinion that within 10 to 20 years after the first profits are made on a Space Station, the government will no longer be in the Space Station business; that the private sector will be designing, building, and launching their own Space Stations and space industries.

The opportunities presented in the commercial mission set have been synthesized from the Space Station Needs, Attributes and Architectual Options (SSNAAO) studies (Mission Analysis Studies) and the Commercial Working Group (CWG). The SSNAAO studies identified over a hundred potential commercial opportunities, not all of which were distinct. Criteria used to select commercial opportunities to be included in the synthesized mission set were: (1) The state of development of the technology (maturity and risk); (2) the potential for early investment and implementation on Space Station; (3) products, processes, and services with identified sponsors and markets; and (4) opportunities representative of the range of possible ventures. The selection criteria were applied on a subjective basis by members of the Commercial Working Group (CWG).

A total of thirty-one (31) commercial opportunities have been identified, ten (10) in materials processing, three (3) in earth and ocean observations, fourteen (14) in communications, and four (4) in industrial services. The mission payload element codes are:

- COMM 10XX Earth and Ocean Observations
- COMM 11XX Communications
- COMM 12XX Materials Processing
- COMM 13XX Industrial Services

The commercial opportunities have been prioritized on a subjective basis by perceived potential for commercialization. As a consequence, some commercial opportunities may be assumed to have a higher priority even though they may be expected to reach maturity later than other opportunities. The priority of the commercial opportunities have been reflected in the last two digits of the mission payload element code, where XX01 is the highest priority and larger numbers are lower priority.

It must be reemphasized that commercial success is dependent upon resolution of a number of technical, market, and institutional issues. This mission set is predicated on successful resolution of potential barriers to commercialization. The total commercial, time-phased mission set is in Section 6.0.

3.2.2 Commercial Materials Processing In Space

The commercial goal of NASA's Materials Processing in Space (MPS) program is the private sector establishment and operation of self-supporting, space processing industries. The strategies for achieving this are the development and expansion of the science data base (MPS is currently an infant science), the encouragement and involvement of industry to make it aware of potential low-gravity processing opportunities (there is currently a non-existent industry based on space processing), and the minimization of impediments to industrial exploitation of space.

Space Station missions that have been synthesized from SSNAAO reports are listed in Table 3-3. A brief discussion of this table follows:

3.2.2.1 Approach

The approach that has been used in developing a set of commercial missions has been to study at length the contractor reports to identify commercial ventures, examine MPS science and applications to determine what might emerge as a commercial application, and exercise judgment on each of these to arrive at a defensible set of missions for the 1990-2000 time frame. Contractor reports have been discussed during several CWG meetings and in presentations made by the contractors. At CWG meetings, NASA's own in-house knowledge and commercialization insight contributed signficantly to the identification and prioritizing of mission sets. The MPS science base is examined on a continuing basis to keep abreast of events and equipment and instrumentation developments as they occur.

TABLE 3-3
MPS COMMERCIAL REQUIREMENTS[3]

NAME	CODE NO.	STS R&D	91-93	93-95	96-98	99-00	AVE. PWR.[2] KW	DATA KBPS	VOLUME M^3	DUTY H/D	CREW # (H/D)	UP MASS KG	TOTAL MASS KG
Commercial R&D Lab (Processing Lab)	1201	87-89	1	1	-	-	8 to 12	10,000	30	10 hrs	1(10)	10/30 days	15,000
Electrophoretic Sep. Prod. Units	1202	82-86	1	1	2	2	15	1,000	20	20 hrs	1(4)	100	7,500
Electroepitaxial Crystal Prod. Units	1203[4]	85-89	1	1	1	1	20[1]	0.1	20	24 hrs	1(4)	--	700
Isoelectric Focusing Prod.	1206	84-88	-	1	1	2	4	1.0	4.6	20 hrs	1(2)	--	2,100
Directional Solidification Prod. Units	1208	86-89	-	1	1	1	3.5 to 38	1.0	3.0	24 hrs	1(2)	--	1,100
Vapor Crystal Growth Prod. Units	1211	89-90	-	1	1	1	7	1.0	1.0	24 hrs	—	--	—
Optical Fiber Prod.	1213	87-89	-	1	1	2	11 to 17	1.0	3.0	24 hrs	1(2)	15,000	29,500
Solution Crystal Growth Prod.	1222	85-89	-	1	1	1	2	1	3.7	24 hrs	1(2)	100	2,000
Iridium Crucible Prod.	1229	87-89	-	1	1	1	3	100	3.0	6 hrs	1(2)	1,000	5,000
Biological Process	1230	89-90	-	1	-	1	1.5	100	SM	6 hrs	1(2)	1,000	10,000
Merge Tech. - Catalyst Prod.	1232	89-90	-	-	1	1	5	100	SM	12 hrs	1(2)	2,000	2,500

(1) 20 kw required for 91-93 units, increases to 40 kw in 93-95, to 80 kw in 96-98, and to 120 kw in 99-00. Free flyer operaiton anticipated from 93 onward.

(2) Data for power, mass, etc. is for one unit only — where more than one unit is shown, data must be multiplied by number of units shown.

(3) Orbit is 400 N.M. with 28.5 inclination.

(4) Includes requirements for 1236.

3.2.2.2 Ground Rules

Ground rules used in selection of mission sets include:

- Maturity of the science;
- Identifiable commercial applications;
- Economic viability;
- Time-phased requirements and NASA's ability to accommodate these requirements;
- Relationship with ongoing NASA MPS science and applications objectives;
- Output and recommendations of SSNAAO studies; and
- Missions selected to be representative of the requirements of similar candidate missions in the same general category.

3.2.2.3 Mission Set

COMM 1201 - Commercial MPS Processing Laboratory

The Commercial MPS Processing Laboratory would probably be a part of a larger laboratory performing MPS for science and applications purposes as well as for commercial processing. The commercial portion of this lab is expected to occupy about one-half of the lab volume initially (i.e., about 6 Spacelab rack equivalents), will require 8 kw initially, and will utilize two dedicated crewmen 8 hours per day each provided and paid for by industry. An acceleration level of about 10^{-4}g is adequate for most commercial investigations and occasional spikes from crew-motion can usually be tolerated. A larger laboratory of about twice this size, capability, and requirements, utilizing 4 crewmen for commercial activities, and requiring 12 kw initially will be needed by 1994.

It is anticipated that the following processing activities will be undertaken:

- Containerless processing;
- Bioseparation including isoelectric focusing;
- Solution crystal growth;
- Isoenzyme production; and
- Collagen processing.

COMM 1202 - Electrophoretic Separation Production Unit

The Joint Endeavor Agreement between the McDonnell Douglas Corporation (MDAC) and NASA commits NASA to assist MDAC in attempting to attain commercialization for the pharmaceutical products that can be separated in MDAC's continuous-flow electrophoresis system (CFES). Consequently, this item in Table 3-3 lists the requirements for the CFES production units that will be needed.

The biological processing module for this system will be a production unit capable of producing commercial quantities of selected pharmaceuticals. Each production system will contain a number of continuous flow electrophoresis separation units, will need several kilowatts of electric power, and will require several months of processing time in low-g. Spikes of acceleration due to crew motion or other similar activity present little problem to the process. Commercial operations that will evolve into several of these production systems are planned to begin in 1986. It is anticipated that interim, unmanned free-flyers will be available during this period, each accommodating a single production unit. This approach limits the number of pharmaceutical productions and the amount that can be produced. A high level of utilities available on the Space Station, coupled with a feasible service and refurbishment capability, will substantially increase both the number of pharmaceuticals that can be processed and the production quantities available to satisfy a larger segment of the market. Industry can have production systems ready as soon as the Space Station is available.

The electrophoretic separation systems and other similar systems that may also be available will initially utilize about 15 kw of power. Growth may require the ability to increase Space Station power or the use of platforms. Semi-automated or EVA resupply, harvesting, and routine service will be required every 30 to 90 days.

COMM 1203 - MRA Electroepitaxial Process To Produce Gallium Arsenide

Under a similar commitment, the Joint Endeavor Agreement with Microgravity Research Associates, Inc. (MRA) calls for the development of gallium arsenide using electroepitaxial crystal growth techniques (ECG) -- a material which can only be made in a space environment with properties that will have a significant impact on the electronics and computer industries. Again, in principle, other electronic materials could be made. Directional solidification is an example of another crystal growth technique for production of gallium arsenide and other materials for electronic and infrared uses that could mature to commercial scale by 1990. These crystal growth factory units will demand about 29 kw of average power from the initial Space Station. As the requirement for power increases, ECG and directional solidifications could transfer to free-flyers to provide commercial quantities of electronic materials if additional power cannot be made available on the Space Station. They would expect to return to the Space Station every 30 days for product recovery, material replenishment, furnace service, and redeployment. The free-flyer must provide about 15 kw of electrical power to the crystal growth furnaces, 24 kw during the service periods. A quiessent g-level of about 10^{-4}g with virtually no jitter will be required for the full 30-day operating periods. Industry could require at least one of these free-flyers within one year of the Space Station IOC and will probably add a new free-flyer every two or three years thereafter.

COMM 1206 - Isolectric Focusing (IEF)

Isolectric focusing (IEF) holds great promise as a low-gravity biological processing technique. This technique is complementary to the electrophoresis work being pursued by McDonnell Douglas/Johnson & Johnson.

For several years, NASA has sponsored research and development of IEF with Dr. Milan Bier of the University of Arizona. NASA plans to fly a demonstration experiment on STS-11 and STS-15 to study selected processing and hardware operations problems. If these tests are successful, NASA may want to design and fly second and third generation hardware in order to demonstrate the feasibility of scale-up production.

It is assumed that full-scale commercial production on the Space Station would commence in 1993 and would process materials on a continuous basis between servicing (every 90 days). Processing would be accomplished in a pressurized module and would require approximately 1.6 kw for operation.

COMM 1208 - Directional Solidification Crystal Growth and COMM 1211 - Vapor Crystal Growth For HgCdTe Production

This mission set focuses on a material that has very significant infrared detection capabilities. Two different processes are proposed to produce (HgCdTe): (1) Directional solidification; and (2) vapor crystal growth. The mission set encompasses both processes. G-jitter of greater than 10^{-5}g disturbs the growth process markedly and, as a consequence, a free-flyer becomes the preferred mode of operation. Manned attendance on the Space Station would be desired if the g-level can be satisfied. Continuous, 24-hour processing is required because of the slow growth rate. An eleven-day service interval on the free-flyer is required. Total power requirements will increase from 17 kw to obtain production quantities desired.

COMM 1213 - Optical Fiber Production

Optical fibers in ton quantity lots will be produced if glass fibers of the desired quality can be produced in low-g. This material will compete with existing methods of ground communications. Power requirements ranging from 11 kw (1995) to 17 kw (2000) are desired. Intravehicular activity (IVA) servicing of 90 man days per year in the pressurized module and extravehicular activity (EVA) servicing of 10 man-days per year in an attached module are desired.

COMM 1222 - Solution Crystal Growth

This technique can produce crystals with fast switching electronic characteristics. The process is a slow one requiring 30-40 days to grow crystals. In the delay period, it is anticipated that solution crystal growth will be studied in the MPS Processing Laboratory and then go into production in 1997 in an attached module.

COMM 1229 - Indium Crucible Production

The Johnson Matthey Company now makes indium crucibles that contain materials having about a $2 billion per year market value. Johnson Matthey estimates that space-made indium crucibles can be made that will add approximately 10% to the volume of these materials. The space required assumes a small module. Power requirements are 3 kw with a duty cycle of 6 hours/day.

COMM 1230 - Eli Lilly Biological Process

This is a proprietary process that has been surfaced by MDAC. It can be contained in a small module (power 1.5 kw average) attached to Space Station with no EVA requirements.

COMM 1232 - Merged Technology

This is also a proprietary product that has been surfaced by MDAC. The product comes from two companies; one produces a membrane, the other a catalyst. The EVA requirement is unknown. Other requirements are shown on Table 3-3.

3.2.3 Earth And Ocean Observations

3.2.3.1 Introduction

Satellite technologies have revolutionized our ability to monitor the Earth's environment and many of its resources. Meteorologists, oceanographers, hydrologists, geologists, farmers, foresters, and those in many other disciplines now look to space to learn more about the Earth.

Over the past 20 years, meteorological satellite systems have evolved to where the products, quantity, and reliability have greatly improved . Meteorological satellite information has proven extremely useful in filling voids in areas where conventional reports are sparse and in the location and tracking of hurricanes, typhoons, and tropical storms.

The infrared data from these satellites can be used to produce charts showing the sea-surface temperature over a large area and with more frequency than is possible from any other source. This information is useful to shipping interests and the fishing industry and is a vital input to meteorological forecasts.

In recent years, the world population expansion and resulting shortages of food, fuel, and minerals have focused increased attention on the oceans and other, unexplored land areas. As commerce has increased, cargo vessels have become larger and more costly to operate and the weather and ocean conditions that they will encounter enroute are carefully considered in an effort to improve their productivity. In many nations, ocean fishing has become a highly systematic activity that makes extensive use of advanced technology to reduce costs and increase the value of the catch. The oceans have also become a major region for the exploration, development, and production of petroleum resources and the exploration of the seabed as a source of minerals has begun. As resources in regions of benign weather are depleted, the frontier has been extended into regions of relatively adverse weather such as the North Sea, the Arctic, and the Gulf of Alaska. This move has been accompanied by a growing recognition that the ability to accurately forecast climate and weather in frontier regions is an important factor in the cost of these operations.

3.2.3.2 Approach

The need for remotely-sensed data clearly exists in the private sector. The Seasat, Nimbus, and Landsat experience have demonstrated the utility of space-borne ocean and land observations in commercial applications. As a result, a private sector community of users exists that can derive substantial dollar benefits from these observations. With the proper marketing strategies and government-industry partnerships, these users can constitute a profitable marketplace for service industries that provide value-added products derived from space-borne sensors measuring ocean surface and land phenomena.

The potential values of this marketplace are uncertain. Revenue estimates range from $4 to $40 billion by the year 2000. Initially, users willing to purchase these remotely-sensed data will represent the renewable and non-renewable resources industries and private forecasting and optimum ship routing industries for site-specific and operationally unique activities. With an assured source of remote-sensed data into the 1990s provided by a Space Station/co-orbiting free-flyer complex, these industries will expand and new service functions will emerge to uniquely process and broker data to a broad segment of ocean, ice, and land use users.

In the near-term (5-10 years), the remote-sensing user industries will not, either alone or in an aggregate sense, be in a position to fully fund a space segment (i.e., sensor, free-flyer, etc.) for remote sensing. However, as revenues develop from the selling of processed and value-added data, these industries can be expected to grow to sufficient magnitude to warrant the up-front purchase of space segments by the private sector.

3.2.3.3 Groundrules And Constraints

In evaluating business opportunities, two constraints must be recognized:

1) There is no known, single commercial entity that is willing to take the risk of fully funding land or ocean remote-sensing; and

2) Most Earth and ocean observation missions will require highly inclined orbits (preferably polar) and some must be sun synchronous.

While all Earth remote-sensing has some commercial value (primarily in the value added sector) only the mineral and energy resource objectives appear to have a high enough commercial value to support a complete space-based sensor system. The current total market for geophysical data is $3-$4 billion per year. Earth remote-sensing could capture a small percentage of this market if pertinent barriers are removed.

3.2.3.4 Mission Set

COMM 1019 - Stereoscopic Imaging System

Airborne stereoscopic data of the Earth's surfaces is one of the primary analytical tools of geologists and geoscientists. However, global airborne surveys would be prohibitively expensive. The Space Station may provide the opportunity for a commercially-viable, stereoscopic imaging system by providing high resolution, three-dimensional images of the Earth's surface that would greatly enhance their capability of pin-pointing possible mineral and energy rich areas on a global basis.

The Stereoscopic Imaging System could be mounted on the initial polar orbiting Space Station and would draw on earlier developmental testing on the Shuttle. The system would be capable of global mapping with fixed observational parameters. Later developments would have the capability for changing spectral bands, bandwidths, fields of view, and pointing angles to meet new mission requirements. The Stereoscopic Imaging System is typical of a variety of strap-on payload packages that would benefit from space.

Stereo-SAR observations on a 1-2 day, repeat cycle from a space platform will provide measurements of ice dynamics of sufficient precision to permit practical navigation and efficient production platform operations. Man-tended sensors permit frequency selection to optimize the character of the measurement, as well as providing the pointing capability to observe specific customer-selected sites/regions and targets of opportunity.

Viable business opportunities are expected to exist in the processing and brokering of the SAR data to both ocean and land users. Eventually, revenues may be available to off-set some fraction of the sensor and sensor operating costs. Private sector funding and ownership of the SAR will be possible as the market for data is developed. This arrangement offers the largest profit potential through proprietary data schemes.

COMM 1023(b) - Ocean Color Imager

Ocean color structure can be indicative of nutrient concentrations and water clarity. It has been demonstrated that certain species of fish aggregate along color boundaries separating nutrient rich water masses and/or regions of clear water. These species include tuna, albacore, salmon, menhaden, and swordfish -- all of which make major contributions to the total catch and revenue from U.S. fisheries. Using the Nimbus-7 Coastal Zone Color Scanner it has been shown that commercial fishermen, when provided with timely ocean color data from space, can reduce the search time required to locate fish concentrations. This reduced search time translates to fuel savings that have been projected to be $2-$5 million per year for the U.S. commerical fishing fleet.

An ocean color sensor on a co-orbiting free-flyer offers the opportunity to provide operational ocean color products to the commercial fishing industry. Ocean color products can be prepared and uniquely processed to enhance key color characteristics peculiar to and significant for each fishery. These value-added color products would be saleable to individual fishing vessels on the basis of offering time savings and more fuel efficient fishing operations.

A color imager on a sun synchronous, free-flying platform, man-tended for refurbishment, would provide the basic utility for a commercially-viable mission. The same sensor on the Space Station would be afforded the additional utility of custom pointing to view areas of interest during seasonal fishing activities and to capture targets of opportunity.

Supplementing the Stereo SAR and Color Imager with a Stereo Multi-Linear Array will enhance the use of these sensors by the commercial user by providing another dimension to their data base.

COMM 1014 - Remote Sensing, Test, Development, And Verification Facility

Spectral bands, resolution, and other physical parameters of an operational, commercial, remote-sensing capability cannot be absolutely determined by analytical methods. Assuring the right selection of these parameters requires some empirical data. This mission will provide a short duration (two flights of two weeks each) capability for the commercial sector to determine the optimum configuration for the operational system.

3.2.4 Commercial Communications Satellites

3.2.4.1 Introduction

Since communications satellites at geostationary altitudes have been used commercially for about 15 years and have benefits that are being exploited by a rapidly expanding industry, the application of a Space Station to commercial communications satellites will involve primarily economic considerations. Operations involving a Space Station and its related elements that can either save costs for satellite owners/operators or permit enhanced capabilities or performance for communications satellites are potential candidates for use by the commercial sector. These may include such operations as in-orbit check-out, repair, servicing, refurbishment, and launch from LEO to GEO. However, the benefits and risks to satellite owners/operators must be clearly established before the commercial sector will seriously plan to fundamentally change their way of doing business. This will require the development and demonstration of the technologies and operational techniques and procedures required for in-orbit facilities and the men and equipment necessary to carry out such technology development and demonstration can effectively enable its commercialization. At the same time, the continued growth of communications satellites will provide a significant market opportunity for eventual commercial use of the Space Station.

Most communications satellites today are of the fixed service type where channels are provided between ground stations with large antennas to support the needs of specified customers. There is considerable interest in investigating new approaches to this service. The availability of a Space Station to support the deployment and possible assembly of satellites larger than those typically used today is of interest. Also of interest are the possibilities of reducing transportation costs to GEO, reducing life cycle operating costs, the incorporation of more economical designs, longer life for the satellites, and reducing the time to replace satellites by using Space Station services.

Two other types of satellites for future service are also now becoming of interest. The first is direct broadcast satellites (DBS) which will provide direct service to homes of either wideband signals (e.g., television) or narrowband broadcasts (e.g., radio). The potential for using the Space Station to simplify replacement of DBS satellites has been identified as a candidate mission for the Space Station and worthy of further study.

The second type of satellite is one which would provide land mobile or aeronautical mobile services. The frequency bands currently of interest for such services are relatively low (UHF to L-band) and have limited allocations for mobile service. Such satellites would require large (25-50 m), multiple beam, deployable antennas (for frequency reuse).

Other concepts that may have potential future application include the use of large antennas to increase frequency reuse at C-band and the use of large communications platforms in GEO to support multiple communications payloads.

3.2.4.2 Approach

The approach used in developing a final set of Space Station missions relative to communications satellites involved a number of activities and utilized many sources of information. These included:

- Working reviews by the Commercial Working Group (CWG), discussions with the Mission Analysis Study (MAS) contractors, and industry review and participation.
- The involvement of NASA with the commercial satellite industry over the past five years in the NASA communications program has resulted in an invaluable source of data and understanding of the concerns and requirements of the commercial satellite industry.
- A comprehensive review of the final MAS contractors' reports was made, including discussions with the industry representatives participating in various reviews and workshops including the Mission Synthesis Workshop at the Langley Research Center in May, 1983.

- A Communications Committee report resulting from the Space Applications Board's "Crestwood" Study in the fall of 1982 was reviewed which provided the CWG with a valuable insight of the industry's priorities and concerns.

3.2.4.3 Assumptions And Considerations

Following a review by the CWG of the MAS contractor's satellite forecasts as well as an independent NASA Lewis Research Center forecast, a baseline forecast of 15 satellites per year launched by the STS was selected. Selecting a constant rate per year was judged to be within the limits of uncertainty of the various forecasts and a valid baseline for estimating Space Station missions and requirements. Because of the anticipated shift from smaller to larger satellites and various technological improvements in satellite communications subsystem and bus designs, a constant launch rate reflects a significant increase in communications capacity in the 1991-2000 time frame.

Four classes of satellites were assumed by the CWG:

(1) PAM-D/11 Class (1,000-1,800 lbs);

(2) PAM-A Class (2,100-2,500 lbs);

(3) IUS/I Class (2,500-6,800 lbs); and

(4) Centaur Class (8,000-12,000 lbs).

It was the judgment of the CWG that communications satellites larger than approximately 12,000 pounds (i.e., Centaur class payloads) would be unlikely before the year 2000. This was based on several factors:

(1) The SAB concluded that there would be no need for communications platforms before the year 2000. This caused the CWG to discount optimistic forecasts of large communications platforms, although it was judged that it would not be prudent to totally disregard their potential before 2000. Thus, two first generation platform missions (one experimental and one operational) were assumed before the year 2000. At the same time, it was assumed they would likely not exceed 12,000 pounds.

(2) Recent studies of mobile satellite systems that would provide voice services (mobile radiotelephone or mobile dispatch) at UHF indicate such systems may not be economically attractive. Satellites that

provide paging, data, or alphanumeric services appear to have more potential. However, such satellites are not likely to have a requirement for as large an antenna as a system providing voice services, nor are they likely to be as heavy. The CWG assumed three missions (one experimental and two operational) before the year 2000, each weighing less than 12,000 pounds.

(3) Large, multibeam C-band satellites were suggested by RCA working as a subcontractor to Boeing. RCA judged that these satellites may be economically and technically feasible because of the potential availability of the Space Station for deployment and perhaps assembly of large antennas. Such systems would be a significant departure from current C-band satellite designs. Nevertheless, they are expected to weigh less than 10,000 pounds. RCA suggested two systems with two such satellites each before the year 2000. This was included in the mission model.

3.2.4.4 Missions

Space Station missions for communications satellites fall into three categories:

(1) Communications Testing;

(2) Initial Launch Operations (Delivery); and

(3) Servicing.

The time-phased communications missions synthesized by the CWG are shown in Section 6.0.

Communications Testing

Communications testing can involve basic and applied research and development, subsystem and system testing, and system applications experiments.

Such mission would have several objectives:

- Enable R&D not possible on the ground;
- Reduce time and cost of development;

- Improve quality of tests and data; and
- Promote new concepts and approaches.

The Communications Test Lab (attached to the Space Station) mission has the objective of performing a variety of experiments related to communications satellite technology such as spacecraft bus and communications tests. It is assumed to be initially established in 1993 when the communications test module is transported to the Space Station and attached to supporting services. It is assumed the facility is exchanged every two years to permit modification and upgrading.

Initially, the facility would most likely be owned and operated by NASA and leased to commercial users with the potential to be commercially owned and operated.

Some communications experiments will require a free-flying receiver module provided by the individual experimenter for antenna radio frequency (RF) tests or laser intersatellite link tests. This free-flyer would require attitude control but could be positioned by a TMS.

Several missions categorized as subsystem or system testing were identified:

- Testing of large deployable antennas;
- Testing of laser intersatellite links; and
- Development of space-borne interferometry technology.

These missions were also defined as technology development missions and are thus accounted for in that category.

One communications testing mission in 1994 utilizing the test lab was identified as a possible applications experiment (RFI measurements). The object of this experiment is to characterize and identify sources of RF transmission (greater than 100 MHz) originating from the Earth in the space allocated bands and demonstrate the ability to locate (within 5 km) such transmissions.

Communications Satellite Delivery

Initial launch operations include all operations required to launch a satellite from LEO to GEO. This would include receiving the satellite at the Space Station, mating it with a transfer stage, performing checkout as required, and launching.

Such missions would have several objectives:

- Reduce transportation cost from LEO to GEO;
- Improve satellite reliability particularly where it may be advantageous to deploy large antennas (e.g., to ensure their employment prior to launch to GEO); and
- Assemble large antennas, etc., where required prior to launch to GEO.

It has been assumed that no satellites in the mission set are likely to require assembly at the Space Station before the year 2000. This was consistent with assuming that no satellites greater than 12,000 pounds would be launched. Because of the likely high cost to the user of in-orbit assembly, it is judged that commercial satellite owners will tend to avoid the need for in-orbit assembly as long as possible.

The use of a space-based, reusable OTV (ROTV) for launching from LEO to GEO is assumed. It has also been assumed that an ROTV would be available for test and demonstration flights in 1993, be fully operational in 1994, and offer lower cost transportation to GEO than expendable upper stages. It has also been assumed that a Multiple Payload Carrier (MPC) will be developed for STS/Centaur. It has been assumed that the MPC will be available for a first flight with Centaur by 1989 and that it would be subsequently adapted for use with the ROTV by 1994.

Using the MPC, it has been assumed that no more than three payloads (satellites) would be launched together.

Assumptions regarding the types of initial launch operations performed are as follows:

	ROTV or ROTV/MPC Mating	Checkout	Deployment	Assembly
PAM-D Class	Yes	Yes[1]	No	No
PAM-A Class	Yes	Yes[1]	No	No
IUS Class	Yes	Yes[2]	Maybe	No
Centaur Class	Yes	Yes[3]	Maybe	Maybe[4]

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(1) Mating interface

(2) Mating interface plus deployment where necessary (possible EVA in event of deployment malfunction)

(3) Mating interface plus deployment (possible EVA in event of deployment malfunction)

(4) EVA required for assembly of major subassemblies

A summary of the selected communications satellite delivery scenario is shown in Figure 3-1.

Communications Satellite Servicing

Servicing includes repair, refurbishment, refueling, (and configuration in the case of DBS spares stored at the Space Station). It is assumed that all communications satellites will be serviced in GEO and that if the servicing is neither possible nor effective, the satellite would be replaced as it is today. As servicing techniques and transportation systems improve and more users permit lower service charges per user, there may be situations where it will become cost-effective to return the satellite to LEO for servicing and possible refurbishment into a usable spare. However, it was judged that this would be unlikely before the year 2000.

FIGURE 3-1
COMMUNICATIONS SATELLITE DELIVERY SCENARIO

	89	90	91	92	93	94	95	96	97	98	99	2000	TOTAL
GET READY MILESTONES													
MPC AVAIL. FOR STS/CENT	▽												
DECISION TO DESIGN FOR ROTV		▽											
INITIAL COMMITMENTS TO ROTV MANIFEST				▽									
ROTV AVAIL. FOR FLT. TESTS					▽								
ROTV OPERATIONAL						▽							
SATELLITES LAUNCHED ON EXPEND.			15	15	14	11	7	3					65
PAM-D CLASS			8	8	7	6	4	3					36
PAM-A CLASS			4	4	4	3	1						16
IUS CLASS			3	3	3	2	2						13
SATELLITES LAUNCHED ON ROTV						4	8	13	15	15	15	15	85
PAM-D CLASS						1	2	3	5	4	4	4	23
PAM-A CLASS						1	2	3	3	3	2	2	16
IUS CLASS						1	4	6	6	6	7	7	37
CENTAUR CLASS													
• EXPERIMENTAL PLATFORM						1							1
• OPERATIONAL PLATFORM										1			1
• EXPER. 2nd GENERATION MOBILE								1					1
• OPER. 2nd GENERATION MOBILE											1	1	2
• OTHER									1	1	1	1	4
STS/CENTAUR/MPC LAUNCHES			2	2	3	2	1						10

The objectives of servicing include:

- Reducing life cycle costs;
- Improving overall system reliability; and
- Reducing risk, particularly for the larger, more complex and more costly satellites.

Possible equipment repair may include replacing RF hardware including antenna components, power amplifiers, associated power conditioners, receivers, and some signal processing equipment. The potential cost effectiveness of refueling is judged to likely be higher than equipment replacement.

For servicing requirements, fuel and equipment will need to be transported to GEO by the ROTV. It is anticipated that a service module will carry these items to GEO where a GEO-based TMS will actually perform the servicing under ground control. It is expected that the fuel for refueling satellites will be a storable bi-propellant such as N_2O_4/MMH.

A unique communications satellite servicing mission is the reconfiguration of DBS spares stored at the Space Station prior to their being launched to GEO. Rather than provide two satellites in orbit at backup in a typical DBS system, it would be possible instead to maintain one spare satellite in storage on the Space Station. This satellite would not be equipped with feed horns and their feed networks, which would be stored separately on the platform. There would be four different feed horn/network assemblies available, and the appropriate one would be installed on the spare satellite when failure or continuing degraded performance of an orbiting satellite occurred. Rapid replacement of a failed satellite could thus be assured by a single satellite stored at the Space Station rather than two satellites in orbit.

The satellite servicing missions are based on the following assumptions:

- A LEO-based TMS is available no later than 1992 for performing service tests and demonstrations in LEO.

- Some communications satellite owners make a final commitment in 1992 to design for serviceability based upon precursor service demonstrations in LEO from the STS, the availability of a TMS, and NASA's commitment to an ROTV. The first commercial serviceable satellites would be launched in 1996 (see Figure 3-2).

- A GEO-based TMS is available no later than 1995 for performing service test and demonstrations in GEO utilizing the experimental communications platform planned for launch in 1994 (see Figure 3-3).

- Commercial satellites designed for serviceability are introduced gradually starting in 1996.

- Servicing events are assumed to nominally occur on a three year interval. However, it was also assumed that one of the IUS class satellites launched in 1996 and in 1997, as well as one of the PAM-A class satellites launched in 1998, would require servicing shortly after being placed on the Station to correct some malfunction. If this does not occur, the first servicing mission nominally would not be until 1999 (i.e., to service the satellites launched in 1996).

- The service missions for reconfiguring DBS spares stored at the Space Station are based on having the equivalent of three DBS systems with four satellites each by 1995 (i.e., 12 operational DBS in GEO). Four additional satellites are added by 1997 (two in 1996 and two in 1997) for a total of four systems with four operational satellites each. The nominal replacement interval for these satellites is assumed to be six years. (Current DBS are being designed for seven year life.)

3.2.5 Industrial Services

3.2.5.1 Introduction

Over the next decades, increased space activities can be anticipated. This comes from maturation of efforts resulting from years of experience in space and, in particular, from the increasing accessibility of space provided by the Shuttle. As the levels of activity increase, competitive ventures will also concurrently increase as corporate entities attempt to profit from the activity. The space activities will arise from government and commercial sources. At some level of activity, viable commercial opportunities will exist in supporting or competitively providing space services and support. This section delineates the most likely of these particular opportunities.

FIGURE 3-2
BASELINE MISSION SCENARIO FOR SERVICING
COMMUNICATIONS SATELLITES

	89	90	91	92	93	94	95	96	97	98	99	2000	TOTAL
GET READY MILESTONES													
SHUTTLE-BASED SERVICING DEVELOPMENT	▽		▽										
SPACE STATION IOC			▽										
TMS AVAILABLE FOR LEO SERVICE TESTS				▽									
TMS OPERATIONS					▽								
ROTV OPERATIONAL						▽							
INITIAL COMMIT TO SERVICEABILITY	▽ (1)			▽ (2)									
INITIATE GEO SERVICING DEVEL. USING ROTV/TMS							▽						
SERVICEABLE SATELLITES LAUNCHED						1		4	6	10	12	15	48
PAM-D CLASS											1	4	5
PAM-A CLASS								1	2	3	2	2	10
IUS CLASS								2	3	5	7	7	24
CENTAUR CLASS													
EXPERIMENTAL PLATFORM						1							1
OPERATIONAL PLATFORM										1			1
EXPER. 2nd GENERATION MOBILE								1					1
OPER. 2nd GENERATION MOBILE											1	1	2
OTHER									1	1	1	1	4

FIGURE 3-3
COMMUNICATIONS SATELLITE SERVICE SCENARIO

	91	92	93	94	95	96	97	98	99	2000	TOTAL
SERVICE MISSIONS IN GEO					1	2	2	3	4	8	20
PAM-D CLASS										1	1
PAM-A CLASS								1	1	2	4
IUS CLASS						1	1	1	2	3	8
CENTAUR CLASS											
EXPERIMENTAL PLATFORM					1*	1*					2
OPERATIONAL PLATFORM								1		1	2
EXPER. 2nd GENERATION MOBILE							1				1
OPER. 2nd GENERATION MOBILE									1		1
OTHER										1	1
DBS SPARES RECONFIG. MISSIONS					2	2	3	3	3	3	16
ROTV FLIGHTS FOR GEO SERVICE					1	2	2	3	4	8	20
ROTV FLIGHTS FOR DBS SPARES					2	2	3	3	3	3	16

* GEO SERVICE TESTS AND DEMONSTRATION

The concept of commercially-provided industrial services could have significant impact on Space Station policies and program planning although the design impacts will likely be barely different from similar government-provided capabilities. Of particular significance will be the government's intent at the beginning of the program to plan for a highly commercialized Space Station at some point in the program evolution.

An early, dedicated effort on the part of NASA to support technology development that will directly benefit the possible commercial user by helping them understand the Space Station and the space environment and simplify the eventual integration and use of the Space Station, will help to convince the potential user that it is to their benefit to conceive innovative ways to go into space to exploit their product.

"Services" is an area of commercial endeavor that presents opportunities for business ventures in space from the development of the initial space station system operating capability and continuing throughout its evolutionary life. The characteristics of a Space Station industrial service are:

- Continual;
- On-demand;
- Reimbursable; and
- Not necessarily mission unique.

For the purpose of establishing the nature of these commercial opportunities in industrial services, the types of services required by mission activities are divided into eight categories of "services" as follows:

(1) Transportation;

(2) Logistics;

(3) Maintenance and Operations;

(4) Construction/Assembly;

(5) Multi-use Platform;

(6) Research/Development;

(7) Personnel Support; and

(8) Specialty.

Implicit in each of these is the inclusion of the personnel, equipment, and ground support to provide the capability for each category. These categories are described below.

Transportation Services will provide the launch and retrieval of space vehicles and/or payloads, orbit and/or trajectory adjustments the operation/ownership of ground and/or space launch/hangar/loading facilities, and will utilize such equipment as an OTV, a TMS, PAM, and an ELV.

Logistic Services will provide replacement of consumables, sparing, warehousing and supply of new materials, fueling/refueling on the ground and in space, and could include the ownership of dedicated transportation vehicles (ground and space). This service does not interrupt operation of the service recipient and does not require significant knowledge about the principles of operation of the service recipient.

Maintenance and Operations Services will provide routine and special maintenance and operations of ground and space systems and will include such activities as troubleshooting, systems analysis, checkout, calibration, parts replacement and repair, cleaning, resurfacing, monitoring, routine operation (such as switching and mode changes), janitorial, and provision of utilities. This category may include operations and utility plants such as power or heat exchange and will include leasing of space and billing for utilities. Service activity requires significant knowledge about the principles of operation of the service recipient, requires special tools, and may violate the physical integrity of the service recipient. Maintenance and operations sources may work closely with Specialty Services.

Construction/Assembly Services will provide initial construction/assembly or demolition of ground or space structures and/or include operation/ownership of special tools. It may also include operation/ownership of manufacturing such as beam builders or replicating plants although this may grow into a product rather than service area. This category will use tools such as tugs and cranes and may require storage and/or hangar facilities.

Platform Services will provide orbital or trajectory carriers of payloads and experiments and will include the range of carriers from a physical framework to self-contained utilities for the payload.

Research and Development Services will provide laboratory type research and development personnel and expertise and will include contracting, design, outfitting with equipment, and operation of an R & D ground or space facility. This category may use government, private, manned, or unmanned facilities and may include a provision of the space facility itself as an industry growth element.

Personnel Support Services will provide the well-being and support of ground or space personnel and will include such things as living quarters, food, clothing, medical, and recreational support. It could include an EVA as a growth element.

Specialty Services will provide special needs such as non-routine servicing, consultation, troubleshooting, and hazardous operations and could include special or one-time system assembly and checkout or installation such as activities associated with nuclear power plants.

For purposes of defining mission requirements, commercial ventures were not considered since they are not design critical. They are more critical in determining policies and program planning. The requirements contained herein are those "service" requirements directly necessary to support commercial communications, commercial materials processing, and commercial earth and ocean observation missions.

3.2.5.2 Approach to Set Development

The approach taken to define industrial service requirements was to determine the service needs of the missions as defined by the materials processing, earth and ocean observations, and the communications missions. This was accomplished by: (1) Interactive discussions with each of the groups responsible for definition of these missions at the National Space Transportation Laboratory (NSTL) meeting of the Commercial Working Group in April, 1982 and at the Langley Research Center (LaRC) meeting of the Mission Requirements Working Group in May 1982; (2) review of the contractors MAS reports and briefing materials; and (3) use of other relevant data from previous study information. Scenarios were developed for each involved mission and servicing requirements were derived in accordance with the scenarios and associated ground rules.

3.2.5.3 Ground Rules/Assumptions

The following ground rules and assumptions were used to develop the industrial service requirements placed on the Space Station by the commercial missions:

(1) The mission requirements defined in the industrial services section only include those opportunities used in the commercial advocacy mission set. Science and applications and technology development mission needs would increase the potential for a business venture(s).

(2) The OTV and TMS requirements are defined by numbers of missions;

(3) The OTV is reuseable and space-based.

(4) The OTV will be available in 1994.

(5) The OTV turnaround is 200 man-hours; the mission requires 1 man-day.

(6) The TMS will be available in 1991.

(7) The TMS turnaround is 100 man-hours; the mission requires 1 man-day.

(8) LEO servicing requires the capability of a TMS.

(9) GEO servicing requires the capability of an OTV from the Space Station to GEO and a TMS (probably GEO based).

(10) Satellite servicing requirements are:

a. MPS production (platform) - once per 90 days.

b. MPS pilot plant (platform) - once per week.

c. MLA (polar) - once every two years.

d. Communications - once every three years.

3.3 TECHNOLOGY DEVELOPMENT MISSIONS

3.3.1 Introduction

The calendar period 1990 and beyond is the time frame of interest for technology development missions that would use the space station.

Mission systems in that time frame are in the "opportunity" category, since such systems provide opportunities for technology development to shape their designs. Volume III of the NASA Space Systems Technology Model identifies and discusses such flight missions. These missions include the following areas:

- Solar System Exploration;
- Solar Terrestrial Physics and Astrophysics;
- Life Science;
- Resource Observation;
- Global Environment (Specific Missions TBD);
- Communications;
- Space Transportation; and
- Utilization of the Space Environment.

In addition, national security missions in space would be of interest in the post-1990 time frame.

Volume III of the NASA Space Systems Technology Model shows that for the opportunity missions as a group, development is needed in essentially every conventional technology discipline. Some of those technology developments could be performed on the ground or by other approaches that would not require a Space Station. In the present volume, attention is limited to those technology developments that would require support from a Space Station. Such technology development missions are itemized hereafter.

In this report, technology development needs and technology development missions are classified according to the disciplines employed in the NASA/OAST space technology program. These categories are shown in Table 3-4, which also shows the analogous working area designations in the Space Station technology program.

Technology thrusts in the tabulated NASA/OAST areas may be: (a) Generic (of value to all systems that involve the discipline); (b) mission-specific (supporting a designated specific mission); (c) operations-related; or (d) basic research.

For each of the listed discipline areas and its subdivisions there exist key issues needing resolution to achieve suitability for space application. The effort to resolve the key issues is herein defined as a technology development mission. As such, a technology development mission encompasses a set of technology tasks rather than consisting of a single task.

The missions identified here are described in more detail in the volume titled "Book 2 Supplement, Technology Development Missions".

3.3.2 Materials

A Space Station would have major value for testing materials to ensure performance and life in the space environment, and for processing materials to have unique properties of high commercial value in ground applications.

TABLE 3-4

TECHNOLOGY DISCIPLINES AND WORKING AREAS

NASA/OAST DISCIPLINE AREAS	SPACE STATION WORKING AREAS
MATERIALS AND STRUCTURES	STRUCTURES AND MECHANISMS
ENERGY CONVERSION	POWER, THERMAL
COMPUTER SCIENCE AND ELECTRONICS	DATA MANAGEMENT, COMMUNICATIONS
PROPULSION	AUXILIARY PROPULSION
CONTROLS AND HUMAN FACTORS	ATTITUDE CONTROL AND STABILIZATION, HUMAN CAPABILITIES
SPACE STATION SYSTEMS/ OPERATIONS	SYSTEMS/OPERATIONS TECHNOLOGY, ENVIRONMENTAL CONTROL AND LIFE SUPPORT
FLUID AND THERMAL PHYSICS/PACE (PHYSICS AND CHEMISTRY EXPERIMENTS)	

3.3.2.1 Materials Performance

In the materials performance area, key requirements include dimensional stability, durability, and sustained performance during long-term operation in space. The space environment may involve hypervelocity impact by meteoroids and debris, irradiation by high energy particles and ultraviolet radiation, interaction with atomic oxygen and plasma, thermal cycling and high vacuum. The set of tasks required to meet the key performance requirements is a technology development mission.

Space Station support would be valuable in this mission. Capabilities offered by a manned Space Station include long duration sample exposure, removal, inspection, and replacement, without need for Earth return or re-launch. Long-term investigations are feasible for structural and insulating materials, surface coatings and adhesives, composites and polymer films, and special materials as required.

Ingredient tasks in this technology development mission are included in Table 3-5 under the titles, "Spacecraft Materials Technology" and "Coatings and Space Component Lifetime Technology."

3.3.2.2 Materials Processing

Materials Processing in Space (MPS) makes use of the low gravity that exists at orbital altitudes to produce materials properties that cannot be achieved in ground production. MPS has application to the development and commercialization of special-property biologicals, metallurgicals, electronic materials, crystals, glasses, and other substances.

Key goals are to obtain improved understanding of materials processes in low-g and to optimize and expedite MPS technology development through involvement of man in the processing cycle.

Low-g materials processing investigations aimed at addressing these issues will typically require high power, long duration, and multiple iteration of experiments. Through its ability to meet these requirements, a Space Station

TABLE 3-5
MATERIALS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Materials

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
MATERIALS PERFORMANCE TECHNOLOGY	ANY	ANY	X			ATT	1,2,4,8	S	TDM 2010
- Spacecraft Materials and Coating Technology	ANY	ANY	X			ATT	1,2,4,8	S	MRWG 2011
- Space Component Lifetime Technology	ANY	ANY	X			ATT	1,2,4,8	S	MRWG 2012
MATERIALS PROCESSING TECHNOLOGY	ANY	ANY	X			ATT	1,2,8	N/A	TDM 2020
- Man-Machine Mix Investigations	ANY	ANY	X			ATT	1,2	N/A	MRWG 2021
- Growth of Compound Semi-Conductor Crystals	ANY	ANY	X			ATT	1,2,8	N/A	MRWG 2022
- Growth of Thin, Single Crystal Wafers	ANY	ANY	X			ATT	1,2,8	N/A	MRWG 2023
- Electrophoresis Separation of Medical Materials	ANY	ANY	X			ATT	1,2,8	N/A	MRWG 2024

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

is an appropriate facility; it can greatly reduce the delay that would accompany individual Shuttle experiments that require Earth recovery, sample analysis, re-preparation, and re-launch for experiment repetition. Proposed technology tasks aimed at addressing the key issues are included in Table 3-5.

Implications of these tasks for Space Station architecture are: A requirement for a suitably equipped laboratory; man's involvement as either observer or experimenter for long periods of time; g-levels lower than 10^{-3} g with low (TBD) jitter; and power levels on the order of 5 kw. There are no orbital inclination or altitude requirements (other than the low-g level), but it is required that the Station be in a circular orbit.

3.3.3 Structures

Large structures have potentially broad applications in space systems. Candidate uses include the following:

(a) As low-stiffness, precision-shaped antennas for a wide variety of purposes (mobile communications satellites, narrow-band broadcast services, deep space network, remote sensing of soil moisture, storm cell tracking, astronomy studies, plasma physics investigations, and other applications).

(b) As low-stiffness planar structures for large solar arrays.

(c) As high-stiffness trusses for space facilities and multipurpose platforms.

Major requirements are:

(1) The need to verify the design of lightweight, flexible space structures that cannot be tested on the ground. A comparison of measured and predicted vibrational modes and frequencies is essential.

(2) The need to investigate and demonstrate methods to control structure attitude, shape, and vibrations.

(3) The need to develop and verify on-orbit construction/assembly/replacement techniques. Candidate structures include beams, trusses, antennas, geodesic structures, modular solar panels, and lightweight cryogenic heat pipes.

Resolution of these needs requires iterative, man-assisted experiments in orbit. Such experiments are facilitated if a series of tests can be performed without returning the structures to Earth. A permanent, manned Space Station capable of working with large structures and of providing long-duration stability would meet these requirements.

Technology development tasks are listed in Table 3-6.

Consideration of these tasks indicates that provisions would be required to permit dynamic testing to determine mode shapes, inertial properties, damping/influence coefficients, and other design parameters, as well as provisions for conducting structure control experiments. In order to meet the need to develop construction/assembly/replacement techniques, the required facilities include a docking/structural-attachment-interface for the large structures, support mechanisms such as the Remote Manipulator System (RMS), a materials storage area, and routine EVA capability.

Crew members skilled in space construction techniques and dynamic testing methods would be required.

3.3.4 Energy Conversion

Currently, the conversion of solar energy in space is directed to the production of electricity. Technology issues associated with such conversion become increasingly significant as the system power level, degree of concentration of sunlight, and operating voltage level increase. A Space Station could be of substantial value in resolving these issues through its support of technology development in the areas of large structures, structure control, high voltage/plasma interactions, and thermal management.

An alternative approach to the conversion and utilization of solar energy is to change the sunlight directly into laser energy and to employ the lasers for high intensity power transmission, propulsion, or magnetohydrodynamic (MHD) power generation.

TABLE 3-6
STRUCTURES PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Structures

PAYLOAD ELEMENT	INCLINATION DESIRED (•)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
DEPLOYMENT/ASSEMBLY/ CONSTRUCTION TECHNOLOGY	ANY	TBD	X			ATT/FF	2,4,7	VARIABLE	TDM 2060
- Large Space Structures	ANY	TBD	X			ATT/FF	2,4	ANY	MRWG 2061
- Space Station Modification	ANY	TBD	X			ATT	4	ANY	MRWG 2062
- On-Orbit Spacecraft Assembly/Test	ANY	TBD	X			ATT	2,4,7	ANY	MRWG 2063
- Advanced Telescope Assembly/Performance	ANY	TBD	X			ATT	2,4	C	MRWG 2064
STRUCTURAL DYNAMICS	ANY	TBD	X			ATT	2,4	Inertial	TDM 2070
- Dynamics and Stability of Large Space Structures	ANY	TBD	X			ATT	2,4	Inertial	MRWG 2071
STRUCTURE CONTROL TECHNOLOGY	ANY	ANY	X			ATT/FF	2,3,4,5	N/A or C	SEE TABLE 3-11
DESIGN VERIFICATION TECHNOLOGY	ANY	TBD	X			ATT	2,4	ANY	TDM 2080
- Spacecraft Strain and Acoustic Sensors	ANY	TBD	X			ATT	2	ANY	MRWG 2081
- Modular Solar Panel Technology	ANY	TBD	X			ATT	2	ANY	MRWG 2082
- Geodesic Spherical Structures	ANY	TBD	X			ATT	4	ANY	MRWG 2083

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

Key technology issues associated with conversion of solar energy to lasers and subsequent laser utilization are:

(1) A need for large solar concentrators having accurate optical surfaces and accurate pointing capability;

(2) A need for laser materials that respond efficiently to solar pumping; and

(3) Laser utilization efficiency.

A Space Station could contribute to the development of the required technology by: Making available the natural solar spectrum, (which cannot be simulated artificially and upon which laser generation depends); providing long-term, man-assisted support in developing the concentrator technology; and providing the low-absorbing space environment that is suitable for high intensity laser power transmission.

Technology development tasks that address the key issues are described in Table 3-7.

An additional energy conversion system issue is the rejection of waste heat. A liquid droplet radiator may involve smaller, lighter configuration than conventional pumped-fluid or heat pipe radiators. A proposed, long-term demonstration of a lightweight, deployable, liquid droplet radiator is included in Table 3-7 under the title Liquid Droplet Radiator.

In the foregoing experiments, construction and assembly would be performed at the Space Station. Highly accurate pointing control of the solar concentrator is required.

3.3.5 Computer Science And Electronics

Two of the disciplines included in this technical group are communications and sensor development, discussed below.

TABLE 3-7
ENERGY CONVERSION PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Energy Conversion

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED *	SS FUNCTION CAP. DESIRED ⌒	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
LARGE SOLAR CONCENTRATOR TECHNOLOGY	ANY	ANY	X			ATT	2,4	S	TDM 2110
- Deployment and Testing of Large Solar Concentrator	ANY	ANY	X			ATT	2,4	S	MRWG 2111
LASER POWER TRANSMISSION/ RECEPTION/CONVERSION	ANY	ANY		X		ATT	2,4	S	TDM 2120
- Test Solar-Pumped Lasers	ANY	ANY		X		ATT	2,4	S	MRWG 2121
- Laser-to-Electric Energy Conversion	ANY	ANY		X		ATT	2,4	S	MRWG 2122
WASTE HEAT REJECTION TECHNOLOGY	ANY	ANY	X	X	X	ATT	2,4	ANY	TDM 2130
- Radiator Technology	ANY	ANY	X			ATT	2,4	ANY	MRWG 2131
- Liquid Droplet Radiator	ANY	ANY			X	ATT	2,4	ANY	MRWG 2132
MICROWAVE POWER TRANSMISSION	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TDM 2140
POWER SUBSYSTEM TECHNOLOGY	ANY	ANY	X			ATT	2,4	S	TDM 2150
- Solar Array/Electrolysis Systems Technology	ANY	ANY	X			ATT	2,4	S	MRWG 2151

* ATT/FF: Attached/Free Flyer

† C/S/E: Celestial/Solar/Earth

⌒ 1. Pressurized laboratory.

2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

3.3.5.1 Communications. Key objectives in the communications area are: (1) To develop the technology of large, lightweight space antennas; and (2) to develop the capability to use laser and microwave communication techniques in the Space Station environment.

For the development of large antenna technology, a manned Space Station would provide a construction base, human assistance, and adequate time for precise assembly, iterative testing, and modifications of the large system. For development of a capability to use optical and radio frequency communication techniques in the Space Station neighborhood, the Space Station would be the test bed and would provide the actual operational environment, which includes interference from celestial and reflecting light sources and the RFI/EMI that occurs during normal Space Station operation.

Technology tasks aimed at achieving these objectives are listed in Table 3-8.

Consideration of these technology tasks indicates a need for the following Space Station capabilities: Operational facilities and crew to build and control large antenna structures; a teleoperator-controlled capability to illuminate an antenna and map its beam patterns; and a data acquisition facility.

3.3.5.2 Sensor Development

In the performance of Earth observations, sensors are needed to measure atmospheric constituents, wind velocity, ocean features, currents and temperatures, cloud thickness and height, topographic features, soil moisture, and other parameters.

A manned Space Station would facilitate development of such sensors through iterative, man-aided observation experiments. Multiple sensors could be under parallel development.

TABLE 3-8
COMMUNICATIONS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Computer Science and Electronics

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
LARGE SPACE ANTENNA (LSA) TECHNOLOGY	ANY	ANY	X			ATT/FF	2,3,4,5	C	TDM 2210
- LSA Construction and Beam Mapping	ANY	ANY	X			ATT/FF	2,3,4,5	C	MRWG 2211
- Multiple Antenna Beam Mapping	ANY	ANY	X			FF	3,4,5	C	MRWG 2212
- Multi-Frequency LSA Control	ANY	ANY	X			FF	2,3,4,5	C,E	MRWG 2213
TELECOMMUNICATIONS SYSTEMS TECHNOLOGY	ANY	ANY	X			FF	3,4,5	N/A	TDM 2220
- Laser Communications and Tracking Development	ANY	ANY	X			FF	3,4,5	N/A	MRWG 2221
- Teleoperator Real-Time Communications Experiment	ANY	ANY	X			FF	3,5	N/A	MRWG 2222
SPACE INTERFEROMETER SYSTEMS TECHNOLOGY	50	ANY	X		X	ATT/FF	2,3,4,5	C,E	TDM 2230
- LSA Short and Long Baseline Technology	50	ANY	X			ATT/FF	2,3,4,5	C,E	MRWG 2231
- Active Aperture Target Identification and Location	ANY	ANY			X	ATT/FF	2,3,4,5	C	MRWG 2232

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

Technology tasks aimed at sensor development and application are listed in Table 3-9. A generic facility, an Earth Observation Sensor Development Laboratory, is envisioned. This facility would require a capability to mount instruments on its exterior surface, provide viewing ports for other instruments, and provide sensor power, cooling, and pointing. A monitoring capability would be needed for both short- and long-term operations and a capability to remove instruments and adjust them inside the laboratory module.

3.3.6 Propulsion

In the propulsion area, a high-interest set of technology development tasks relates to on-board auxiliary propulsion and to the several steps (storage, acquisition, transfer) involved in propellant supply for a space-based orbital transfer vehicle (OTV). Key technology objectives are:

- Fluid management in low-g;
- Long-term storage of cryogenic propellants;
- Reduction of the contamination produced by the nozzle plume; and
- Control of acceleration forces to desired low levels.

A Space Station provides: (1) A controlled, long-duration, low gravity environment; (2) the actual thermal environment of interest; (3) a base for mounting and testing candidate low-thrust engines; (4) adequate space to investigate the nozzle plume trajectory and contamination process; and (5) the in-situ manned capability to analyze test results and make corrective modifications.

Technology development tasks aimed at addressing the key issues are listed in Table 3-10.

Consideration of the technology development tasks indicates that both the manned Space Station and free-flyers could be required to address the key issues. Many of the advanced cryogenic and non-cryogenic fluid management

TABLE 3-9
SENSORS TECHNOLOGY PAYLOAD ELEMENT DATA

MISSION CATEGORY *Technology Development* DISCIPLINE *Computer Science and Electronics*

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODA-TION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
EARTH OBSERVATIONS INSTRUMENT TECHNOLOGY	28-60	LEO	X	X	X	ATT	1,2,4,8	E	TDM 2260
- Earth Sensing Instrument Technology	ANY	LEO	X	X	X	ATT	1,2,4,8	E	MRWG 2261
- Manned Observations Techniques Development	ANY	LEO	X	X		ATT	1,2	E	MRWG 2262
- Air Pollution Measurement (MAPS)	ANY	LEO	X			ATT	1,2,8	E	MRWG 2263
- CO_2 Lidar	ANY	LEO		X		ATT	1,2,4,8	E	MRWG 2264
- Microwave Remote Sensing-Active/Passive	>50	LEO	X			ATT	1,2,4,8	E	MRWG 2265
- Satellite Doppler Meteorological Radar	>50	LEO	X			ATT	1,2,4,8	E	MRWG 2266

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

TABLE 3-10
PROPULSION PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Propulsion

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
FLUID MANAGEMENT TECHNOLOGY	ANY	ANY	X			ATT	1,2	C,E	TDM 2310
- Fluid Acquisition, Storage, Gauging, and Transfer at Low G	ANY	ANY	X			ATT	1,2	C,E	MRWG 2311
- Long-Term Cryogenic Fluid Storage	ANY	ANY	X			ATT	1,2	C,E	MRWG 2312
LOW THRUST PROPULSION	ANY	ANY	X			FF	3,5	N/A	TDM 2320
- Controlled Acceleration Propulsion Technology	ANY	ANY	X			FF	3,5	N/A	MRWG 2321
- Laser Propulsion	ANY	ANY	X			FF	3,5	N/A	MRWG 2322

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

technology tasks will require the addition of a manned technology development laboratory to the Space Station. Fluid management experiment requirements would dictate size, power, thermal, and acceleration control specifications for this laboratory. In addition, a free-flying platform may be required to provide a test bed for the evaluation of concepts and/or techniques for the long-term orbital storage of hazardous cryogenic fluids. Precise acceleration control will be required for conducting fluid management technology development experimentation. The crew members involved in the laboratory should be skilled in fluid management experimentation.

3.3.7 Controls And Human Factors

The objectives in this area are: (1) To provide advanced control technology for large space systems; and (2) to optimize the use of man, machine, and the man/machine combination in the performance of space operations.

3.3.7.1 Controls

This discipline deals with the controls and guidance of Earth orbiting systems, space transportation systems, and planetary spacecraft. Current emphasis is on the development of technology to control large flexible configurations (platforms, large antennas, Space Station). Control of shape, vibration, and pointing is required.

Key issues are:

(1) Lumped, rigid body control systems of present spacecraft will probably be inadequate for the large, flexible, interactive configurations under consideration. For these configurations, distributed, adaptive, and modular control systems will require definition and investigation.

(2) Structure/control interactions will require study.

(3) Sensors, actuators, and damping techniques will require development.

(4) Analytical models and algorithms required for design of the control system will have to be developed and verified.

Resolution of the key issues for the configurations of interest would require tests in a low-g field to minimize distortion of the structures under their own weight, man's participation in system assembly and alignment, and adequate time for testing, system modification, and experiment repetition. A manned Space Station would be able to meet these requirements and would be a cost-effective means for development and verification of the technology.

Several controls technology development tasks are described in Table 3-11.

Consideration of these tasks indicates that the Space Station would require a manned capability to support deployment, assembly, control, testing, and evolution of large systems on-orbit.

3.3.7.2 Human Factors

The objective of this discipline is to develop technology for the allocation of functions to humans and machines in space operations. The operations include intravehicular tasks as well as the extravehicular activities of construction and assembly, maintenance and repair, satellite and OTV servicing, and mission-unique functions.

Key goals are:

(1) To determine the capabilities and limitations of human operators in the areas of teleoperation, EVA, space transportation system flight management, human operations aboard Space Stations, and human/computer interfaces.

(2) To develop the technology of visual and tactile feedback and the technology for control in teleoperator and robotic systems.

(3) To determine the best allocation of functions to man, machine, and to the human interface with intelligent computer systems for maximum productivity.

The human factors and automation technology program will address the key issues by means of analytical simulations and ground and flight experiments

TABLE 3-11
CONTROLS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Controls and Human Factors

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
ATTITUDE CONTROL TECHNOLOGY	ANY	ANY	X			ATT	2,3,4	C	TDM 2410
- Advanced Adaptive Attitude Control	ANY	ANY	X			ATT	2,3,4	N/A	MRWG 2411
- Distributed Attitude Control	ANY	ANY	X X			ATT	2,3,4	C	MRWG 2412
- Control Disturbance Damping Experiment	ANY	ANY	X			ATT	2,3	N/A	MRWG 2413
FIGURE CONTROL TECHNOLOGY	ANY	ANY	X			ATT/FF	2,3,4,5	C	TDM 2420
- Active Optics Technology	ANY	ANY	X			ATT/FF	3,4,5	C	MRWG 2421
- Thermal Shape Control	ANY	ANY				ATT	2,3,4	C	MRWG 2422
CONTROL DEVICES TECHNOLOGY	ANY	ANY	X			ATT	2,3,4	N/A	TDM 2430
- Advanced Control Device Technology	ANY	ANY	X			ATT	2,3,4	N/A	MRWG 2431

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

prior to the existence of a Space Station. However, technology advancement in these areas will subsequently need to be conducted for extended time periods aboard the Space Station in order to achieve the optimum distribution of operational functions under actual conditions in orbit.

Technology development tasks are described in Table 3-12. These experiments would call for a Space Station teleoperator test laboratory suitable for validating ground-based models and for developing adaptive control algorithms for zero-g operations prior to testing candidate teleoperator systems both on the Space Station and remotely via attachment to a TMS. One or two crew members trained in teleoperator control would also be required.

3.3.8 Space Station Systems/Operations

Systems and operations activities cut across all technology disciplines. The system effort brings together the disciplines and associated subsystems into an integrated Space Station. The operations activity implements the Space Station itself as well as carrying out its functions on-orbit. Life cycle cost is a major technology driver in the systems and operations areas.

3.3.8.1 Space Station Systems

Among the large number of requirements for the total Space Station are: (1) the ability to operate a large power system in the space environment; and (2) assurance of Space Station habitability and life support for extended stay-time in orbit. These requirements will necessarily be met by the first Space Station. However, long-term tests on-orbit will then be needed to enable technology advances in these areas for application to future, higher performance Stations. The Space Station would be capable of providing the long-time, man-assisted experiments required to advance these technologies.

Technology development tasks in the power systems operation area are listed in Table 3-13.

TABLE 3-12
HUMAN FACTORS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Controls and Human Factors

PAYLOAD ELEMENT	INCLINATION DESIRED (•)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD EARLY 90S	MID 90S	LATE 90S	ACCOMMODATION MODE DESIRED *	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
TELEOPERATION TECHNOLOGY	ANY	ANY	X			ATT/FF	2,3,4,5	N/A	TDM 2460
- Assembly of Structures Using Teleoperation	ANY	ANY	X			ATT/FF	2,3,4,5	N/A	MRWG 2461
- Teleoperator Sensor -- Evaluation and Testing	ANY	ANY	X			ATT	2,3,4	N/A	MRWG 2462
- Manipulator Controls Technology	ANY	ANY	X			ATT/FF	2,3,4,5	N/A	MRWG 2463
- Advanced EVA Technology	ANY	ANY	X			ATT	2,3,4	N/A	MRWG 2464 GDCD 2402
HUMAN PERFORMANCE TECHNOLOGY	ANY	ANY	X			ATT	1,2,3	N/A	TDM 2470
- Interactive Human Factors	ANY	ANY	X			ATT	1,2,3	N/A	MRWG 2471
- Advanced Automation Technology	ANY	ANY	X			ATT	1,2,3	N/A	MRWG 2472

* ATT/FF: Attached/Free Flyer

† C/S/E: Celestial/Solar/Earth

^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

TABLE 3-13
SYSTEMS PAYLOAD ELEMENT DATA

MISSION CATEGORY: Technology Development — DISCIPLINE: Space Station Systems/Operations

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD: EARLY 90S	MID 90S	LATE 90S	ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
ENVIRONMENTAL EFFECTS TECHNOLOGY	ANY	ANY	X			ATT/FF	2-5	N/A	TDM 2510
- Contamination Effects of Ion Thrusters	ANY	ANY	X			ATT	2-5	N/A	MRWG 2511
- Large Space Power Systems Technology Demo	ANY	ANY	X			ATT/FF	2-5	N/A	MRWG 2512
- High Voltage in Space Plasma	ANY	ANY	X			ATT	2-5	N/A	MRWG 2513
HABITATION TECHNOLOGY	ANY	ANY	X			ATT	1	N/A	TDM 2520
- Crew System Emesis Station	ANY	ANY	X			ATT	1	N/A	MRWG 2521
- Crew System Appliances	ANY	ANY	X			ATT	1	N/A	MRWG 2522
- Acoustics Control Technology Development	ANY	ANY	X			ATT	1	N/A	MRWG 2523
MEDICAL TECHNOLOGY	ANY	ANY	X			ATT	1	N/A	TDM 2530
- Medical Experiments	ANY	ANY	X			ATT	1	N/A	MRWG 2531
- Surgery Development	ANY	ANY	X			ATT	1	N/A	MRWG 2532
TETHER SYSTEMS TECHNOLOGY	TBD	TBD	TBD	TBD	TBD	ATT	2	TBD	TDM 2540

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

3.3.8.2 Operations

The operations area includes on-orbit construction/assembly, checkout, rendezvous and docking, logistics, servicing, and on-board activities. The capability to support these functions enables the Space Station to serve existing satellites and payloads and to assist in implementing new missions, provide basing for vehicles, support research and technology experiments, and meet requirements aboard the Space Station.

The key requirement is to develop the technology needed to perform these functions with optimal allocation to manned and automated procedures.

Early capabilities for extravehicular activity (EVA) and for remote manipulation with the RMS will be developed with the Shuttle. Many of the remaining technology development tasks, however, would be more cost-effectively accomplished on or with support from the Space Station, which would provide the required long periods of weightlessness and exposure to the space environment, the required degree of platform stability, storage and handling capabilities, and EVA and RMS functions. It will also be necessary to conduct investigations on the Space Station to verify the interface capabilities, docking, berthing facilities, and response to dynamic excitations.

Technology development tasks aimed at developing operations capabilities are described in Table 3-14.

Requirements on the Space Station to accomplish these tasks would include tools and equipment for EVA operations on structures, provisions for the required degree of attitude control and stabilization, servicing interfaces for satellites and payloads, and a hangar for OTV servicing.

Required crew skills would include EVA operations experience, as well as experience with avionics, fluid systems, checkout and adjustment of scientific instrumentation, and combustion research.

TABLE 3-14
OPERATIONS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Space Station Systems/Operations

PAYLOAD ELEMENT	INCLINATION DESIRED (•)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED*	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
SATELLITE SERVICING TECHNOLOGY	28.5	TBD	X			ATT/FF	2,5,6	ANY	TDM 2560
- Satellite Servicing/ Refurbishment	ANY	TBD	X			ATT	2,5	ANY	MRWG 2561
- Module Replacement	ANY	TBD	X			FF	6	ANY	MRWG 2562
- Materials Resupply	28.5	TBD	X			ATT/FF	3,6	ANY	MRWG 2563
- Coatings Maintenance Technology	ANY	TBD	X			ATT	2	ANY	MRWG 2564
- Thermal Interface Technology	ANY	TBD	X			ATT	2	ANY	MRWG 2565
OTV SERVICING TECHNOLOGY	28.5	TBD	X			ATT/FF	2,4,5,7	ANY	TDM 2570
- OTV/Payload Interfacing and Transfer	28.5	TBD	X			ATT/FF	2,5,7	ANY	MRWG 2571
- OTV Propellant Reliquification Technology	28.5	TBD	X			ATT	2	ANY	MRWG 2572
- OTV Docking/Berthing Technology	28.5	TBD	X			ATT/FF	2,5,7	ANY	MRWG 2573
- OTV Maintenance Technology	28.5	TBD	X			ATT/FF	2,4	ANY	MRWG 2574
ON-BOARD OPERATIONS TECHNOLOGY	ANY	ANY	X			ATT	1,2	ANY	TDM 2580
- Fire Safety Technology	ANY	ANY	X			ATT	1,2	ANY	MRWG 2581
REMOVAL OF SPACE DEBRIS	TBD	TBD	TBD			TBD			TDM 2590

* ATT/FF: Attached/Free Flyer

† C/S/E: Celestial/Solar/Earth

^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

3.3.9 Fluid And Thermal Physics/Physics And Chemistry Experiments (PACE)

The mission described in this section illustrates the spectrum of scientific research for which the unique physical conditions of the space environment are required. Experiments addressing fundamental questions in fluid dynamics, thermal physics, general relativistic physics, low-temperature physics, and chemistry can be performed with sensitivity increases several orders of magnitude over that attainable in Earth-based laboratories.

Unlike the situation encountered on Earth, surface tension forces will dominate buoyancy forces in determining fluid flow under low-gravity space conditions, thus allowing the study of Marangoni convection and the Benard instability phenomenon. The absence of a pervasive gravity force also enables a unique investigation of the electrohydrodynamics of fluid interfaces, heat transfer during nucleate boiling, and the non-Brownian velocity relaxation of a small particle in a fluid flow (a phenomenon of great interest in the theory of statistical mechanics). With regard to basic physics research, a Space Station experiment will allow the testing of the equivalent of gravitational and inertial mass (a fundamental postulate of Einstein's General Theory of Relativity). In addition, high-precision, super-conducting cavity oscillators will be used to accurately measure the gravitational redshift obtained in Earth orbit. An outstanding question in both theoretical and experimental low-temperature physics is the nature of the phase transition occurring at the lambda point of liquid helium. High temperature resolution measurements of the thermodynamic properties of helium undergoing the lambda transition can only be performed in low-gravity. Gravitational distortion also limits ground-based, cryogenic research involving critical point phenomena in two component helium fluid systems. The continuous space environment allows a study of the basic chemical reactions induced by high-energy particle penetration of polymer resins.

The operation and results of the aforementioned experiments are tied to the required space technology development and to the potential applications. The low temperature physics experiments are connected with the long-life cryogenic refrigeration technology detailed in a separate mission. Scientific data concerning surface tension-induced fluid flow and heat transfer are directly applicable to fluid management missions. Commercial processes involving sedimentation or solidification from a binary liquid solution could be adversely affected by Marangoni convection cells and free surface non-existence, low-gravity fluid physics phenomena. Experiments in fluid electrohydrodynamics in space are an essential precursor to the practical use of an electric field for containerless materials processing and for the separation of Helium-3 and Helium-4 fluid mixtures in dilution refrigeration techniques. The mechanical performance of lightweight, epoxy-based structural materials in the space environment can be understood through the space-borne polymer chemistry experiment.

For this mission, a suitably-instrumented, long-duration Space Station scientific laboratory will be required. Successful operation of the experiments necessitate acceleration control, low-levels of gravitational acceleration, contamination protection, and a high degree of positional stability. Data analysis capability should also be provided. Scientifically and technically trained mission specialists will implement experiment control, maintenance, and repair. Orbital configuration should be tailored to specific experimental specifications.

Experiment categories and individual experiments are summarized in Table 3-15.

3.3.10 Prioritized Mission Sets

During May, 1983, a Space Station Mission Synthesis Workshop was held during which the missions were prioritized and time-phased for the two calendar periods 1991-1993 (IOC period) and 1991-2000. The technology development mission sets for the calendar period 1991-1993 are shown in Figure 3-4. (The time-phased mission set for the calendar period 1991-2000 are shown in Section 6.0.)

TABLE 3-15
FLUID AND THERMAL PHYSICS PAYLOAD ELEMENT DATA

MISSION CATEGORY Technology Development DISCIPLINE Fluid and Thermal Physics

PAYLOAD ELEMENT	INCLINATION DESIRED (°)	ALTITUDE DESIRED (KM)	OPERATIONAL TIME PERIOD			ACCOMMODATION MODE DESIRED *	SS FUNCTION CAP. DESIRED ^	LOOK DIRECTION †	REMARKS
			EARLY 90S	MID 90S	LATE 90S				
FLUID DYNAMICS	ANY	ANY	X			ATT	1,2	N/A	TDM 2610
- Surface Tension Induced Fluid Effects	ANY	ANY	X			ATT	1,2	N/A	MRWG 2611
- Electrohydrodynamic Fluid Behavior	ANY	ANY	X			ATT	1,2	N/A	MRWG 2612
- Small Particle Velocity Relaxation	ANY	ANY	X			ATT	1,2	N/A	MRWG 2613
- Mechanisms of Pool Boiling	ANY	ANY	X			ATT	1,2	N/A	MRWG 2614
CRYOGENIC PHYSICS	ANY	ANY	X			ATT	1,2	N/A	TDM 2620
- Lambda Transition of Liquid Helium	ANY	ANY	X			ATT	1,2	N/A	MRWG 2621
- Critical Point Experiments	ANY	ANY	X			ATT	1,2	N/A	MRWG 2622
GENERAL RELATIVITY	TBD	TBD	X			ATT/FF	1,2,3	N/A	TDM 2630
- Gravitational Redshift Experiment	TBD	TBD	X			ATT/FF	1,2,3	N/A	MRWG 2631
- Cryogenic Equivalence Principle Experiment	TBD	TBD	X			ATT	1,2	N/A	MRWG 2632
SPACE POLYMER CHEMISTRY									TDM 2640
- Radiation Effects on Polymers	TBD	TBD	X			ATT	1,2	TBD	MRWG 2641

* ATT/FF: Attached/Free Flyer
† C/S/E: Celestial/Solar/Earth
^ 1. Pressurized laboratory.
2. Base for attached payloads.
3. Base for communication, command, and control (C^3).
4. Base for deployment, assembly, and construction.
5. Base for proximity operations.
6. Base for remote maintenance, servicing, checkout, and retrieval.
7. Base for payload integration and launch.
8. Base for preparing payloads for Earth return.

FIGURE 3-4
MISSION SET FOR BASELINE IOC SPACE STATION SYSTEM

MISSIONS		YEAR		
CODE	NAME	1991	1992	1993
	SCIENCE & APPLICATIONS			
SAA 0001	SPECTRA OF COSMIC RAY NUCLEI (SCRN)	28.5 PLAT		
SAA 0002	SPACE PLASMA PHYSICS		SS PORT	
SAA 0003	SOLAR OPTICAL TELESCOPE (SOT)		28.5 PLAT	
SAA 0004	SHUTTLE IR TELESCOPE (SIRTF)			28.5 PLAT
SAA 0006	STARLAB		28.5 PLAT	
SAA 0307	LIFE SCIENCES		SS R&D LAB.	
SAA 0201	LIDAR FACILITY		SS R&D LAB PORT.	
SAA 0012	SPACE TELESCOPE (ST)		SERVICED F.F.	
SAA 0013	GAMMA RAY OBSERV. (GRO)		SERVICED F.F.	
SAA 0014	X-RAY TIMING EXP. (XTE)	SERVICED F.F.		
SAA 0016	SOLAR MAX MISSION (SMM)		SERVICED F.F.	
SAA 0019	FAR UV SPECTROSCOPY EXP. (FUSE)			SERV. F.F.
SAA 0202	EARTH SCIENCE RES. (ESR-1)		POLAR PLATFORM	
	COMMERCIAL			
COM 1201	MPS PROCESSING LAB #1		SS R&D LAB.	
COM 1202	EOS PRODUCTION UNIT		SS PORT	
COM 1203	ECG PRODUCTION UNITS		SS PORT	
COM 1019	STEREO MULTI-LINEAR ARRAY		POLAR PLATFORM	
	TECHNOLOGY DEVELOPMENT			
TDM 2520	HABITATION TECHNOLOGY		SS HAB. MOD	
TDM 2580	ON-BOARD OPERATIONS TECH.			SS R&D LAB
TDM 2010	MATERIALS PERFORMANCE TECH.		SS PORT	
TDM 2060	DEPLOYMENT/ASSEMBLY/CONSTRUCTION		SS PORT	
TDM 2070	STRUCTURAL DYNAMICS		SS PORT	
TDM 2080	DESIGN VERIFICATION TECHNOLOGY		SS PORT	
TDM 2260	EARTH OBSERVATION INSTRUM. TECH.		SS PORT	
TDM 2310	FLUID MANAGEMENT TECH.	SS PORT		
TDM 2410	ATTITUDE CONTROL TECHNOLOGY		SS PORT	
TDM 2420	FIGURE CONTROL TECHNOLOGY		SS PORT	
TDM 2460	TELEPRESENCE & EVA TECH.			SS PORT
TDM 2510	ENVIRONMENTAL EFFECTS TECH.	SS PORT		
TDM 2560	SATELLITE SERVICING TECH.	SS PORT		
TDM 2570	OTV SERVICING TECH.	SS PORT		
TDM 2210	LARGE SPACE ANTENNA TECH.			SS PORT
TDM 2470	INTERACTIVE HUMAN FACTORS			SS HAB.

4.0 SUMMARY OF USER MISSION (UNCONSTRAINED) REQUIREMENTS

Based upon the data given in Section 3.0, the user missions/payload elements are summarized and categorized according to orbital location and Space Station functional requirements. As information on the specific payload elements are developed in the contracted Mission Analysis Studies, this section will analyze in detail the resources and utility support requirements (e.g., power, data rate, mass, volume, and crew support).

4.1 PAYLOAD ELEMENT FUNCTIONAL GROUPINGS

The science and applications and technology development payload elements listed in Section 3.0 were aggregated into functional groups to be more representative of the anticipated flight mode. Table 4-1 lists the functional groupings for the science and applications payload elements. The payload elements from Section 3.0 that were not grouped are listed at the bottom of the table for convenience. Table 4-2 lists the functional groups for the technology development payload elements, along with the ungrouped payload elements at the bottom of the table. The commercial missions did not require additional grouping from the Section 3.0 data. These functional groupings and individual payload elements are hereafter referred to as mission units. This results in a total of 39 mission units for the science and applications mission category, 20 mission units for the commercial mission category, and 15 mission units for the technology development mission category.

4.2 CATEGORIZATION OF USER MISSIONS

The 74 total mission units identified in Section 4.1 were categorized by orbital inclination and Space Station functional accommodation mode (i.e., payload attached to the Space Station and/or payload operates as a free-flyer but is serviced/supported by a Space Station). The categorization of the mission units is used to define reasonable program scenarios in Section 5.0 and for the data base for establishing the mission sets in Section 6.0.

TABLE 4-1
TECHNOLOGY DEVELOPMENT
PAYLOAD ELEMENT FUNCTIONAL GROUPINGS

FUNCTIONAL GROUP	DISCIPLINE	PAYLOAD ELEMENTS
LLAG – LOW INC. LOW ENERGY ASTRONOMY	ASTROPHYSICS	FUSE, STARLAB, SIRTF
HLAG – HIGH IN. LOW ENERGY ASTRONOMY	ASTROPHYSICS	OVLBI, LDR
LHAG – LOW INC. HIGH ENERGY ASTRONOMY	ASTROPHYSICS	HTM, HRS, SCRN, TRIC
SPPG – SPACE PLASMA PHYSICS	ENVIIRON. SCI.	WISP, SEPAC, AEPI, AXET, ISO, RPDP, MP, SM
ACG – ATMOSPHERIC COMPOSITION	ENVIRON. SCI.	ATMOS, IR, LIDAR
OMG – OCEAN MONITORING	ENVIRON. SCI.	SCAT, OCI, OMP, LASMMR, LD, DCLS
ADG – ATMOSPHERIC DYNAMICS	ENVIRON. SCI.	AVHRR, SPLF, LASMMR
CMG – CRYOSPHERE MONITORING	ENVIRON. SCI.	SCAT, RAD. ALT., SLA, LASMMR, MSAR, PSS, DCLS
POG – PLANETARY OBSERVATORY	EARTH & PLAN	PST, FTS
RRG – EARTH RESOURCES	EARTH & PLAN	MLA, IS, MSAR, MTIRI, LASMMR, LRS, SLA, DCLS

UN–GROUPED PAYLOAD ELEMENTS:

ST, GRO, AXAF, ASO, LAMAR, ADEF, HEIE, SCDM, SIDM, CRM, UARS, LARS, WS, TOPEX, STO, PMS, GMS, PPPL, SSE, HMF1, HMF2, HMF3, RPL, PPL, CELSS, CGSP, CP, FCP, BP

NOTE: PAYLOAD ELEMENT ACRONYMS USED ABOVE ARE DEFINED IN APPENDIX A.

TABLE 4-2

TECHNOLOGY DEVELOPMENT PAYLOAD ELEMENT FUNCTIONAL GROUPINGS

FUNCTIONAL GROUP	DISCIPLINE	PAYLOAD ELEMENTS
LST – LARGE STRUCTURE TECH.	ACROSS DISCIPL.	ZAR, LACO, MHAC, LTD, LSTE, SADT, ACD, TSC, AAC, SLT
SDL – SENSOR DEVEL. LAB.	ACROSS DISCIPL.	EOSD, MTCT, FBT, ADV
SOT – STRUCTURAL OPER. TECH.	ACROSS DISCIPL.	LTD, TSC, SLT, SADT
SPS – SOLAR POINTING STRUCT.	ACROSS DISCIPL.	SPT, HVP I, SPL, LEEC, LPT, SPP
SC – SOLAR CONCENTRATOR	ACROSS DISCIPL.	LSC, SPL, LEEC, LPT, SPP
SET – SERVICING TECH.	ACROSS DISCIPL.	SST, OST, MTCT, FBT
CFT – CREW FACTORS TECH.	ACROSS DISCIPL.	HABT, BHFT
FMT – FLUID MGMT. TECH.	ACROSS DISCIPL.	CFS, FMT
LGMT – LOW-G MATERIALS TECH.	ACROSS DISCIPL.	CG, MPTL, SPC, COMF
MPE – MATERIALS PERF. TECH.	ACROSS DISCIPL.	SCM, MAC, SCL
MGP – MICRO-G PACE	ACROSS DISCIPL.	FLD, CRY, GRE

UN-GROUPED PAYLOAD ELEMENTS:

CAP, DROP, CONT, FST

NOTE: PAYLOAD ELEMENT ACRONYMS USED ABOVE ARE DEFINED IN APPENDIX A.

Table 4-3 lists and categorizes the mission units that could be accommodated in an attachment to Space Station mode. The table categorizes the mission units by operational time periods (early 90s, mid-90s, and late 90s) and desired orbital inclination (28.5°, 57°, 90°, and any inclination -- no specific requirements). Table 4-4 lists and categorizes the mission units that could be accommodated as a free-flyer (or on a space platform) but could also be serviced/supported by a Space Station. The mission units that indicated both an attached and free-flyer mode appear in both tables.

TABLE 4-3
CATEGORIZATION OF MISSION UNITS -- ATTACHED

	28.5°				57°				90°/98°				ANY
	C	S	E	N/A	C	S	E	N/A	C	S	E	N/A	
EARLY 90'S	LAMAR POG			GLSS		STO							NMFI, PPL, CELSS, CGSP, CP, FCP, BP, CMLI, BPM GSSF, LAP SDL, SOT, SPS, CFT, FMT, LGMT, SC MPE, FST
MID 90'S	POG	ASO		GLSS ILSS GLSC GLSA		STO			HEIE	SPPG CRM			HMFI, HMF2 RPL, PPPL PPL, CELSS, CGSP, CP, FCP, BP, CML2, BPM SSF, LAP SDL, SPS, MPE, SC
LATE 90'S	POG	ASO		ILSS GLSC ILSC ILSA									HMF I, HMF2, HMF3 RPL, PPL, CELSS, CGSP, CP, FCP, BP, BPM, CML2 ISSF, LAP MPE

NOTE: Payload element acronyms used above are defined in Appendix A.

TABLE 4-4
CATEGORIZATION OF MISSION UNITS -- SERVICED FF/SP

	28.5°				57°				90°/98°				ANY
	C	S	E	N/A	C	S	E	N/A	C	S	E	N/A	
EARLY 90'S	ST GRO AXAF LAMAR			SSE		STO	UARS LARS	LDEF			OMG CMG RRG PMS TOPEX OCI		MPFI LSB LST, SET MGT, CAP, CONT, FST
MID 90'S	LLAG LHAG ST GRO AXAF	ASO SCDM	GMS	SSE GLSC	HLAG	STO	ACG		HEIE		ADG OMG CMG RRG WS SI SSAR CWFS COCI PMS		MPF I, MPF2, SIDM LSB, CTMS
LATE 90'S	LLAG LHAG ST GRO AXAF	ASO	GMS	SSE GLSC ILSC	HLAG		ACG				ADG OMG CMG RRG SI SSAR PMS CWFS COCI		MPF I, MPF2 LSB, CTMS DROP

NOTE: Payload element acronyms used above are defined in Appendix A.

5.0 SPACE STATION SYSTEM OPERATIONAL CAPABILITIES

The mission requirements developed in Section 3 are fiscally unconstrained. Although most requirements would prefer accommodation in the initial Space Station, funding limitations dictate an evolutionary Space Station system.

Accordingly, this section describes a potential, time-phased set of Space Station capabilities. The mission model served by these capabilities is developed in Section 6.

5.1 DEFINITION OF SPACE STATION FUNCTIONS

Pressurized Laboratory: A pressurized crew station module will provide power, low gravity, and long duration crew support for conducting laboratory work and operational support. Payload elements may be integrated directly into the module.

Base For Attached Payloads: Provisions will be made to accommodate payload elements exterior to the pressurized module. Limited resources plus periodic crew tending and servicing will be provided. Resources could include command, control, and data handling.

Base For C^3 Support: Provisions will be made within the Space Station system to remotely command, control, monitor, throughput, and pre-process data for free-flyers and platforms.

Base For Deployment, Assembly, And Construction: The Space Station system will provide support capability for construction, assembly, and deployment. This support implies all required service devices such as manipulators and manned maneuvering units (MMUs).

Base For Proximity Operations: Payloads capable of maneuvering themselves within a reasonable distance of the Station will be maintained, serviced, and checked out. Reasonable distance is defined as that limited by the capability of an extravehicular mobility unit (EMU) of a small proximity operation vehicle (POV) nominally 2 kilometers (km).

Base For Remote Maintenance, Servicing, Check-Out, And Retrieval: Payloads remote from the Space Station can be maintained/serviced and checked out via a remotely-operated service vehicle. Servicing could be provided on the payload at its locations or the payload could be retrieved, serviced, and returned. The Space Station likewise provides for commanding, controlling, maintaining, and servicing the service vehicle.

Base For Payload Integration And Launch: Payloads/satellites requiring transfer to other orbits can be brought to the Space Station by the Shuttle, integrated with a transfer stage, and launched. The transfer stages could be commanded and controlled from the Space Station. These stages could be either expendable or reusable. Reusable transfer stages can be based at the Space Station, serviced, maintained, and refueled. Expendable stages could be stored and serviced.

Base For Payload Staging For Earth Return: Payloads, experimental samples, or captured samples requiring return to Earth can be demated, prepared, and stored until placed in the Shuttle for return to Earth.

5.2 SPACE STATION SYSTEM CAPABILITIES

Table 5-1 illustrates a preliminary definition of Space Station system capabilities developed by the Concept Development Group of the Space Station Task Force.

The initial Space Station will accommodate 4-8 people and is planned to become operational in 1991. Two, unpressurized resource modules will each provide 37.5 kw average bus power and a central place for other services for the entire Space Station. A 6-port, Multiple Berthing Adapter (MBA) will provide Space Station control consoles and serve as a central hub for attaching several other modules. Two laboratory modules will be provided with 4 radial ports on each for attaching external payloads. These ports will provide for structural, electrical, data, and environmental interfaces and allow for independent payload pointing and stabilization. A single, "smart" Teleoperator Maneuvering System (TMS) is provided which can deploy, retrieve, and remotely service

TABLE 5-1
SPACE STATION SYSTEM CAPABILITIES

	ELEMENT	CAPABILITIES
1991	RESOURCE MODULES (2)	• POWER – 75 kw AVERAGE BUS POWER (60 kw TO USER) • THERMAL CONTROL • ATTITUDE CONTROL • REBOOST • COMMUNICATION • DATA MANAGEMENT
	MULTIPLE BERTHING ADAPTER (MBA)	• 6 PORTS • AIRLOCK • RMS & TMS CONTROL • SUIT STORAGE AND MAINTENANCE
	HABITAT MODULE	• 4–8 PERSON CREW QUARTERS • OPEN ECLS • HEALTH MAINTENANCE
	LABORATORY MODULES (2)	• 20 FOOT MODULE • 120 m^3 R&D
	LOGISTICS MODULES (2)	• 90 DAY RESUPPLY • HYGIENE • SPARES
	POLAR PLATFORM	• 12 kw BUS POWER
	28.5° PLATFORM	• 12 kw BUS POWER
	TELEOPERATOR MANEUVERING SYSTEM (TMS)	• BASED AT STATION • SATELLITE RETRIEVAL, REMOTE REPAIR, AND DEPLOYMENT
1992	SURROGATE CARGO BAY	• TMS AND SATELLITE STORAGE • SATELLITE SERVICING • RMS WITH TRACK • 2 MMUs
1992 (Cont.)	LABORATORY	• Δ60 m^3 R&D LAB (180 m^3 TOTAL)
	HABITAT 2	• 8 PERSON CREW
	MBA 2	• 12 PORTS, 8 FOR PAYLOADS
	LOGISTICS 3	• RESUPPLY
1993	LABORATORY	• Δ120 m^3 (300 m^3 TOTAL)
	RESOURCE 3	• Δ50 kw POWER (110 kw TO USER)
	HABITAT 3	• 12 PERSON CREW
	MBA 3	• 12 PAYLOAD PORTS
1994	OTV TANKS HANGER	• Δ40 kw POWER (150 kw USER TOTAL) • REUSABLE SPACE-BASED CRYO, AEROBRAKED
1995	SURROGATE CARGO BAY 2	• INCREASED ATTACHED PAYLOADS
	HABITAT 4	• 16 PERSON CREW
	LOGISTICS 4	• RESUPPLY
1996	2nd OTV/2nd TMS	• INCREASED MISSION SUPPORT
2000	POLAR STATION RESOURCE MBA HABITAT TMS LABORATORY LOGISTICS	

NOTE: THE MBA, HABITAT, AND LABORATORY MODULES WILL ALL SERVE AS 21 DAY SAFE HAVENS satellites in orbits similar to that of the Space Station. Two unmanned, 12 kw platforms will be able to accommodate changing sets of payloads serviced by the Shuttle or TMS. One will be devoted primarily to Earth resources in polar orbit and the other to astrophysics in 28.5° orbit.

For users, the initial Space Station will provide 60 kw average bus power, 4-8 people, communications and data management, Remote Manipulator System (RMS) and TMS support, extravehicular activity (EVA) capability, health maintenance (and thereby life sciences data), 120 m^3 R&D laboratory space, 8 ports for attached external payloads, and 2 platforms.

In 1992, a surrogate cargo bay (a structure configured exactly like the Shuttle cargo bay to facilitate interfaces) with a track for the RMS and two Manned Maneuvering Units (MMUs) will be added to aid in satellite warehousing and servicing. The MMUs are backpacks and permit EVA crew members to maneuver about the Station and significantly enhance assembly and servicing tasks. Another 60 m^3 of laboratory space with 4 more ports for attached external payloads plus a full 8-man crew will be available.

In 1993, 120 m^3 more laboratory space and 4 more ports for attached external payloads will be added along with an additional 50 kw to the users and 4 more people.

In 1994, another 40 kw to the users will be added along with a reusable space-based, cryogenic, aerobraked Orbital Transfer Vehicle (OTV) permitting more effective transport of payloads to higher energy orbits, particularly GEO.

In 1995, another surrogate cargo bay and 4 more people will be added.

In 1996, a second, duplicate OTV and TMS are added.

Thus, by 1996 the Station will provide 150 kw average bus power, 16 people, communications and data management, RMS and TMS (2) support, EVA with MMU capability, 300 m^3 laboratory space in addition to a health maintenance facility, 20 ports for attached external payloads, 2 surrogate cargo bays, reusable OTV (2) support, and 2 platforms.

Table 5-2 summarizes the year-by-year capabilities available to users. All eight of the functions listed in Section 5.1 can be performed to some degree by the initial Space Station with increasing capabilities added thereafter.

About the year 2000, a polar station will be added with the elements shown in Table 5-1.

TABLE 5-2
SPACE STATION CAPABILITIES AVAILABLE TO USERS

YEAR	AUG. BUS. PWR. (KW)	CREW (STATION & MSN.)	COM. & DATA	RMS	TMS	EVA	LAB. VOL. (M^3)	HEALTH MAINT. FAC.	PORTS FOR ATT. P/L'S	SUR. CARGO BAY	REUSEABLE OTV	PLATFORMS
91	60	4-8	X	X	-	X	120	X	8	-	-	POLAR 28.5
92	60	8	X	W/ Track	1	W/ MMU	180	X	12	1	-	POLAR 28.5
93	110	12	X	W/ Track	1	W/ MMU	300	X	16	1	-	POLAR 28.5
94	150	12	X	W/ Track	1	W/ MMU	300	X	16	1	-	POLAR 28.5
95	150	16	X	W/ Track	1	W/ MMU	300	X	16	2	1	POLAR 28.5
96	150	16	X	W/ Track	2	W/ MMU	300	X	16	2	2	POLAR 28.5

6.0 TIME-PHASED MISSION SET

The time-phased mission set developed at the Langley Mission Requirements Workshop (as modified by subsequent analysis) is presented in this section.

6.1 SCIENCE APPLICATIONS MISSIONS

The science and applications missions, as shown in Figure 6-1, are divided into the current NASA disciplines. The code number relates the mission to the NASA data base maintained at the Langley Research Center. This data base includes all pertinent data for the missions currently available. The data base is maintained by the NASA Mission Requirements Working Group and is updated periodically as additional information becomes available. The 21 missions included under astrophysics range from payloads attached to the Space Station to free flyers at high inclinations and/or high energy orbits. The length of the bar denotes the duration of the mission. The desired inclination and accommodation are also shown. Included in the mission set are free-flying missions that will be launched prior to the Space Station era (e.g., Space Telescope and the Gamma Ray Observatory) but will be serviced by the Space Station. Others such as OPEN and the Very Long Baseline Interferometer will not interact with a Space Station at a 28.5° inclination but are included to complete the total mission set. The triangle in 1991 for the Solar Dynamics Observatory denotes launch with no potential interaction with the Space Station. A number of missions are shown as attached to the Space Station or to a Space Platform. Decisions on the location of these missions depend on a number of factors. The dominant factors are: (1) The ability to point instruments accurately with acceptable jitter; (2) the degree of contamination of the environment around the Space Station; (3) the frequency of service required by the payload; and (4) the cost effectiveness of one accommodation mode versus the other.

In earth science and applications, five missions have been defined. The Lidar facility is envisioned as a research facility for development of Lidar technology and techniques as well as scientific studies of the tropical atmosphere. Once the development is complete, Lidar instruments would be

FIGURE 6-1

TIME-PHASED MISSION SET - SCIENCE & APPLICATIONS

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	ASTROPHYSICS										
SAA 0001	SPECTRA OF COSMIC RAY NUCLEI (SCRN)	ATT	28.5° SP/SS								
SAA 0002	SPACE PLASMA PHYSICS (ACTIVE)		ATTACHED		28.5° SS						
SAA 0002A	SPACE PLASMA PHYSICS (PASSIVE)		ATTACHED		28.5° SP						
SAA 0006	STARLAB	ATT 28.5° SP/SS									
SAA 0003	SOLAR OPTICAL TELESCOPE (SOT)		ATTACHED 28.5° SP/SS								
SAA 0009	PINHOLE/OCCULTER FACILITY							ATTACHED		28.5° SP/SS	
SAA 0011	ADVANCED SOLAR OBSERVATORY (ASO)									ATT 28.5° SP/SS	
SAA 0004	SHUTTLE IR TELESCOPE FACILITY (SIRTF)			ATTACHED		ATTACHED	28.5° SP/SS				
SAA 0005	TRANSITION RADIATION & ION CAL (TRIC)				ATT 28.5°		SP/SS				
SAA 0007	HIGH THROUGHPUT MISSION (HTM)						ATTACHED 28.5° SP/SS				
SAA 0008	HIGH ENERGY ISOTOPE							ATT 28.5° SP/SS			
SAA 0012	SPACE TELESCOPE (ST)	FREE FLYER 28.5°									
SAA 0013	GAMMA RAY OBSERVATORY (GRO)	FF 28.5°									
SAA 0014	X-RAY TIMING (XTE)	FF 28.5°									
SAA 0019	FAR UV SPECTROSCOPY EXP. (FUSE)			FF 28.5°							
SAA 0010	CORONA DIAGNOSTIC MISSION (CDM)									FF 28.5°	
SAA 0015	OPEN		FF 0° & 80°								
SAA 0016	SOLAR MAX MISSION	FF 28.5°									
SAA 0017	ADV X-RAY ASTROPHYSICS FAC (AXAF)	FREE FLYER 28.5°									
SAA 0018	VERY LONG BASELINE INTERFERO. (OVLBI)					FREE FLYER 57°					
SAA 0020	LARGE DEPLOYABLE REFLECTOR (LDR)								FF 28.5°		
SAA 0021	SIRTF SUNSYNCH								FF 97°		
SAA 0022	SOLAR DYNAMICS OBSERVATORY	Δ									
	EARTH SCIENCE & APPLICATIONS										
SAA 0201	LIDAR FACILITY	ATT 28.5°			SS/SP						
SAA 0202	EARTH SCIENCE RESEARCH	FREE FLYER 90°									
SAA 0203	TOPEX	FREE FLYER 63.4°									
SAA 0204	GEOPOTENT RESEARCH MISSION (GRM)	FF 90°									
SAA 0205	GOES FOLLOW-ON						Δ				

FIGURE 6-1

TIME-PHASED MISSION SET - SCIENCE & APPLICATIONS (Continued)

<table>
<tr><th colspan="2">MISSIONS</th><th colspan="10">YEAR</th></tr>
<tr><th>CODE</th><th>NAME</th><th>1991</th><th>1992</th><th>1993</th><th>1994</th><th>1995</th><th>1996</th><th>1997</th><th>1998</th><th>1999</th><th>2000</th></tr>
<tr><td></td><td><u>SOLAR SYSTEM EXPLORATION</u></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0101</td><td>MARS GEOCHEM/CLIMATOL ORBITER (MGCO)</td><td>△ 1990</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0102</td><td>LUNAR GEOCHEM ORBITER</td><td></td><td></td><td>△</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0103</td><td>COMET HMP RENDEZVOUS</td><td>△ 1990</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0104</td><td>VENUS ATMOSPHERE PROBE</td><td></td><td></td><td></td><td>△</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0105</td><td>TITAN PROBE</td><td></td><td></td><td>△</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0106</td><td>SATURN PROBE</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>△</td><td></td><td></td></tr>
<tr><td>SAA 0107</td><td>MAIN BELT ASTEROID RENDEZVOUS</td><td></td><td></td><td></td><td></td><td></td><td>△△</td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0108</td><td>SATURN ORBITER</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>△</td><td></td><td></td></tr>
<tr><td>SAA 0109</td><td>NEAR EARTH ASTEROID RENDEZVOUS</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>△</td><td></td></tr>
<tr><td>SAA 0110</td><td>MARS SAMPLE RETURN</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>△</td><td></td></tr>
<tr><td></td><td><u>LIFE SCIENCES</u></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0307</td><td>LIFE SCIENCES LAB</td><td colspan="10">PRESSURIZED MODULE</td></tr>
<tr><td>SAA 0306</td><td>CELSS PALLET</td><td></td><td></td><td colspan="6">ATTACHED SS</td><td></td><td></td></tr>
<tr><td>SAA 0305</td><td>DEDICATED CELSS MOD.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">PRES. MOD.</td></tr>
<tr><td></td><td><u>MATERIALS SCIENCE</u></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0401</td><td>MPS R&D FACILITY</td><td colspan="5">PRESSURIZED MODULE</td><td colspan="5">Requirements Included in Com 1201</td></tr>
<tr><td></td><td><u>COMMUNICATIONS</u></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SAA 0501</td><td>EXPERIMENTAL GEO PLATFORM</td><td></td><td></td><td></td><td>△</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

placed on the Earth Science Research Platform located in a polar or near-polar orbit. The Earth Science Research Platform is an evolutionary, interdisciplinary facility for study of the Earth, oceans, atmosphere, and biogeochemical cycles. The Geodynamic Experimental Ocean Satellite (GEOS) follow-on is a mission to geosynchronous orbit for development and demonstration of advanced instrumentation in meteorology and climatology.

Solar system exploration missions are shown as launches and may or may not interact with the Space Station. If a reusable Orbital Transfer Vehicle (OTV) is available by the mid-1990s, it could be used as a launch stage for some missions. The only mission shown that would be enabled by a Space Station is the Mars Sample Return Mission which requires on-orbit assembly and could use the Space Station for sample analysis on return.

Life sciences missions have two focii: (1) Studies of long duration weightlessness effects on humans, animals, and plants in an on-board lab facility; and (2) the development of a fully closed life support system. Initial activities in the life sciences lab are devoted to research on plants, humans, and small animals. Later in the decade (1995) an animal and plant vivarium is added.

The materials processing sciences R&D facility was identified as a major need by both the Science and Applications Panel and the Commercial Panel. It is shown in Figure 6-2.

The only activity envisioned in the communications area under science and applications is an experimental geosynchronous platform which would support a number of communications payloads. This platform could also be a key element in the development of techniques for geoplatform servicing by the combination of the OTV and a "smart" Orbital Maneuvering Vehicle (OMV).

FIGURE 6-2

TIME-PHASED MISSION SET - COMMERCIAL

MISSIONS CODE	MISSIONS NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	COMMUNICATIONS TESTING										
COM 1105	COMMUNICATIONS TEST LAB			△ ATTACHED S.S. (1993–2000)		△		△		△	
COM 1107	LARGE DEPLOYABLE ANTENNA	REQUIREMENT INCLUDED IN TDM 2210									
COM 1120	LASER COMMUNICATIONS	REQUIREMENT INCLUDED IN TDM 2220									
COM 1127	SPACEBORNE INTERFEROMETER	REQUIREMENT INCLUDED IN TDM 2230									
COM 1128	RFI MEASUREMENTS				□ ATTACHED S.S.						
	COMMUNICATIONS SATELLITE DELIVERY										
COM 1117	PAM-D CLASS SATELLITES				1	2	3	5	4	4	4
COM 1116	PAM-A CLASS SATELLITES				1	2	3	3	3	2	2
COM 1115	IUS CLASS SATELLITES				1	4	6	6	6	7	7
COM 1110	CENTAUR CLASS SATELLITES				1*		1	1	2	2	2
	* REQUIREMENT INCLUDED IN SAA 0501										
	COMMUNICATIONS SATELLITES SERVICING										
COM 1131	PAM-D CLASS SATELLITES										1
COM 1126	PAM-A CLASS SATELLITES								1	1	2
COM 1125	IUS CLASS SATELLITES						1	1	1	2	3
COM 1124	CENTAUR CLASS SATELLITES					1	1	1	1	1	2
COM 1121	RECONFIG. COMM. SAT. SPARES EXCHANGE					2	2	3	3	3	3
	INDUSTRIAL SERVICES										
COM 1304	TELEOPERATOR MANEUVERING SYSTEM (TMS)	POTENTIAL COMMERCIAL OPPORTUNITIES NOT INCLUDED IN MISSION MODEL									
COM 1309	SPACE-BASED REUSABLE OTV										
COM 1312	SATELLITE SERVICING										
COM 1318	MULTI-USE SPACE PLATFORM										

FIGURE 6-2

TIME-PHASED MISSION SET - COMMERCIAL
(Continued)

CODE	NAME	YEAR (1991–2000)
	MATERIALS PROCESSING	
COM 1201	MPS PROCESSING LAB #1	PRESSURIZED MODULE
	MPS PROCESSING LAB #2	PRESSURIZED MODULE
COM 1202	EOS PRODUCTION UNITS	ATTACHED S.S. OR PRES. MOD. OR ATT. S.P.
COM 1203	ECG PRODUCTION UNITS	PRES. MOD. AND ATT. TO S.P. IN 1993 PRESSURIZED MODULE
COM 1206	IEF PRODUCTION UNITS	PRESSURIZED MODULE
COM 1208	DSCG PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1211	VCG PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1213	OPTICAL FIBER PRODUCTION UNITS	PRESSURIZED MODULE
COM 1222	SOLUTION CRYSTAL GROWTH PROD. UNITS	PRES. MOD. OR ATT. SS/SP
COM 1229	IRIDIUM CRUCIBLES PRODUCTION UNITS	PRES. MOD. OR ATT. SS/SP
COM 1230	BIOLOGICAL PROCESSES PRODUCTION UNITS	ATT. S.S. OR PRES. MOD. OR ATT. S.P.
COM 1232	MERGED TECHNOLOGY - CATALYST PROD. UNITS	PRES. MOD. OR ATT. SS/SP
	EARTH & OCEAN OBSERVATIONS	
COM 1014	REMOTE SENSING TEST/DEV./VERIF. FAC.	ATTACHED S.S.
COM 1019	STEREO MULTI-LINEAR ARRAY	LAUNCH; SERVICE; ATTACHED TO SP; SUN-SUNCH ORBIT
COM 1023	STEREO SAR + MLA + CZCS	F.F. SUN-SYNCH

6.2 COMMERCIAL MISSIONS

The commercial mission set is presented in Figure 6-2. The MPS Processing Lab #1 is required at Space Station initial operational capability (IOC). A volume of 60 m^3 is required with an average power requirement of 8 kw. It is anticipated at this time that this unit would be provided by the government and used by government, academic, and industry researchers. MPS Lab #2 would probably be provided by the commercial sector. The volume and power requirements for this lab are 60 m^3 and 15 kw, respectively.

A total of 10 commercial production units are shown for the 1990s. The Electrophoresis Operations in Space (EOS) unit would be provided by McDonnell Douglas/Johnson and Johnson and produce a variety of pharmaceutical products. The Electroepitaxial Crystal Growth (ECG) unit provided by Microgravity Research Associates would produce high-purity, five centimeter diameter crystals of gallium arsenide. These two activities are currently in the research phase under Joint Endeavor Agreements (JEA) with NASA. Additional units with high potential for implementation over the remainder of the decade are:

- Isoelectric Focusing (IEF) - Biological products directional.
- Directional Solidification Crystal Growth (DSCG) - Gallium arsenide, Hg Cd Te, and other crystals.
- Vapor Crystal Growth (VCG) - Mercury Cadmium (cd), Tellerium (Te), (Hg),and other crystals.
- Optical Fiber - High quality optical fibers.
- Solution Crystal Growth - Crystals with fast-switching, electronic characteristics.
- Iridium Crucible - High purity iridium crucibles.
- Biological Processes - Proprietary process for production of biological materials.
- Merged Technology - Catalyst -- proprietary process.

It is not expected that all of the above will prove to be viable commercial endeavors. Some will and some will not be replaced by new products and processes that will be developed on Shuttle missions or in the MPS R&D labs.

Analysis of the commercial potential for earth and ocean observations indicates that the return on investment would be adequate for commercial entities to develop and operate instruments but inadequate to provide the spacecraft as well. Thus, it is assumed that instruments would be provided by industry and accommodated on a NASA space platform such as the Earth Science Research Platform. Instruments with the greatest potential are the stereo multilinear array, the stereo synthetic aperture radar, and a coastal zone color scanner-type instrument.

The commercial space communications field is the first success story in the industrialization of space. Projections of future missions and needs vary widely. An approximate average of 15 satellite deliveries per year divided into the mass categories accommodated by the four upper stages is indicated in Figure 6-2. It is assumed that a cost-effective, reusable OTV introduced in 1994 will begin to provide transportation to geosynchronous orbit and will have captured the full 15 missions per year by 1977. It appears that a communications test lab attached to the Space Station is required. This is basically an on-orbit, antenna test range. Significant technology development is required to move to large antennas for land mobile communication and for laser communications. These activities, while identified by the Commercial Panel, are included under technology development missions for requirements bookkeeping purposes.

With the advent of the OTV, geosynchronous satellite servicing becomes feasible. Thus, we show servicing missions beginning in 1995 and growing over the remainder of the decade. COMM 1121 involves storing a spare direct broadcast satellite (DBS) at the Space Station. Upon failure of an operational DBS, the spare could be rapidly reconfigured to match the failed satellite characteristics and transported to GEO by the OTV. The missions listed under industrial services are not missions as such. They are potential services that industry could provide to the government and to other industries at a profit.

6.3 TECHNOLOGY DEVELOPMENT MISSIONS

The technology development missions set shown in Figure 6-3 was primarily developed by the NASA Technology Development Missions Panel. The missions are grouped according to the NASA Office of Aeronautics and Space Technology (OAST) technology disciplines. In general, the technology development missions require attachment to the Space Station and a large amount of crew extravehicular activity. Key missions in the materials and structures discipline are those for development of space construction technology that enables commercial communications missions and future science missions. For example, the large deployable reflector, astrophysics mission also requires this technology.

Although satellite and OTV servicing technology development will be initiated on the Shuttle, this development will continue on the Space Station for several years. Most of the technology missions are undertaken over the first half of the decade with a substantial decrease in activity over the latter part of the decade in order to provide the required technology for missions in the late 1990s. The ability to predict the technology development needs for missions in 2000 and beyond is limited.

The missions discussed here are reviewed in much greater detail in the NASA Space Station Mission Requirements Workshop (Langley Report) and in the volume titled "Book 2 Supplement, Technology Development Missions".

6.4 MISSION REQUIREMENTS

The requirements associated with the time-phased mission set of Figures 6-1 through 6-3 can be summarized in terms of those associated with the manned Space Station and those associated with the co-orbiting platform.

FIGURE 6-3

TIME-PHASED MISSION SET - TECHNOLOGY DEVELOPMENT

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	MATERIALS & STRUCTURES										
TDM 2010	MATERIALS PERFORMANCE TECHNOLOGY	PRESSURIZED MOD. & ATTACHED S.S. (4 Service/yr.)									
TDM 2020	MATERIALS PROCESSING TECHNOLOGY	PRES. MOD. & ATT. S.S.				(1 Service/mo.)					
TDM 2060	DEPLOYMENT/ASSEMBLY/CONSTRUCTION		ATT. S.S.			(1 Service/2 mo.)					
TDM 2070	STRUCTURAL DYNAMICS		ATT. S.S.			(1 Service/mo.)					
TDM 2080	DESIGN VERIFICATION TECHNOLOGY		ATT. S.S.		(1 Service/mo.)				ATT/FF		
	ENERGY CONVERSION										
TDM 2130	WASTE HEAT REJECTION TECHNOLOGY					ATT. S.S.		(2 Service/yr.)			
TDM 2110	LARGE SOLAR CONCENTRATOR TECHNOLOGY						ATT. S.S.		(4 Service/yr.)		
TDM 2120	LASER POWER TRANSMISSION/RECEP./CONV.							ATT. S.S.		(2 Service/yr.)	
	CONTROLS & HUMAN FACTORS										
TDM 2410	ATTITUDE CONTROL TECHNOLOGY		ATT. S.S.		(1 Service/3 mos.)						
TDM 2420	FIGURE CONTROL TECHNOLOGY		ATT. S.S.		(1 Service/3 mos.)						
TDM 2460	TELEPRESENCE & EVA TECHNOLOGY			ATT. S.S.		(1 Service/3 mos.)					
TDM 2470	INTERACTIVE HUMAN FACTORS			PRES. MOD.							
TDM 2430	ADVANCED CONTROL DEVICE TECHNOLOGY				PRES.					PRES.	
	SPACE STATION SYSTEMS OPERATIONS										
TDM 2560	SATELLITE SERVICING TECHNOLOGY	ATT. S.S.		(1 Service/mo.)							
TDM 2570	OTV SERVICING TECHNOLOGY	ATT. S.S.		(1 Service/mo.)							
TDM 2520	HABITATION TECHNOLOGY	PRES. MOD.									
TDM 2510	ENVIRONMENTAL EFFECTS TECHNOLOGY	ATT. S.S.					ATT. S.S.		(6 Service/yr.)		
TDM 2530	MEDICAL TECHNOLOGY	PRES. MOD.									
TDM 2540	POWER SYSTEM TECHNOLOGY EXPERIMENTS						ATT.	(1 Service/mo.)			
TDM 2580	ON-BOARD OPERATIONS TECHNOLOGY			PRES. MODULE							
TDM 2590	PLANETARY AUTOMATED ORBIT OPERATIONS								F.F. W/TMS		

FIGURE 6-3
TIME-PHASED MISSION SET - TECHNOLOGY DEVELOPMENT (CONTINUED)

MISSIONS		YEAR									
CODE	NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	<u>COMPUTER SCIENCE & ELECTRONICS</u>										
TDM 2210	LARGE SPACE ANTENNA TECHNOLOGY			ATT. S.S.	ATT. S.S.	(1 Service/6 mos.)					
TDM 2260	EARTH OBSERVATION INSTRUMENT TECHNOLOGY		PRES. MOD. & ATT. S.S.	PRES. MOD. & ATT. S.S.	PRES. MOD. & ATT. S.S.	PRES. MOD. & ATT. S.S.	PRES. MOD. & ATT. S.S.	(4 Service/yr.)			
TDM 2220	TELECOMMUNICATIONS SYSTEM TECHNOLOGY						ATT.	(1 Service/3 mos.)			
TDM 2230	SPACE INTERFEROMETER SYSTEM TECHNOLOGY					ATT.	(1 Service/3 mos.)				
	<u>PROPULSION</u>										
TDM 2310	FLUID MANAGEMENT TECHNOLOGY	PRES. MOD.	PRES. MOD.								
TDM 2320	LOW THRUST PROPULSION				ATT.	S.S.				(1 Service/2 mos)	
	<u>FLUID & THERMAL PHYSICS</u>										
TDM 2610	FLUID DYNAMICS				PRES. MOD.	PRES. MOD.					
TDM 2620	CRYOGENIC PHYSICS					PRES. MOD.	PRES. MOD.				
TDM 2640	SPACE POLYMER CHEMISTRY					ATT. S.S.	ATT. S.S.	(1 Service/3 mos.)			
TDM 2630	GENERAL RELATIVITY									PRES. & FF	

6.4.1 28.5° Space Station

Figure 6-4 presents the requirements that the mission set places on the manned Space Station at 28.5°. Placement of the manned Space Station at an inclination of 28.5° is driven primarily by two factors. The majority of U.S. missions considered can be accommodated at 28.5°. This is the inclination to which maximum payload can be delivered by the Shuttle.

As noted in Figure 6-4, high power is required from the beginning of the Station era. 55 kw is required in 1991. The primary power driver is the commercial materials processing area. In 1991, the two production units and the MPS lab require a total of 43 kw. EVA crew time associated with materials processing is also large. The current estimate is that approximately 1,400 crew hours per year is required for each production unit to maximize production and minimize down time. Obviously, the trade-off between crew time and increased automation must be studied in much greater detail to establish the most cost-effective approach to a production unit operation. EVA hours are primarily driven by the technology development missions and reach a maximum in 1993. Note that this is actual work time and does not include the time associated with getting into and out of the suit or prebreathing (if necessary). The number of pressurized modules is largely due to commercial production units.

Free-flyer servicings are those servicings associated with science mission free-flyers at 28.5° inclination.

Transportation events are those activities involving use of the OTV to transport payloads to geosynchronous orbit or to provide servicing to those spacecraft. It is assumed, as noted previously, that the OTV becomes available in 1994. In addition, up to three spacecraft are assumed to be transported to geosynchronous orbit on a single OTV flight.

FIGURE 6-4

SUMMARY REQUIREMENTS FOR A 28.5° SPACE STATION

YEAR	MASS KG	PRES-SURIZED VOLUME M^3	POWER KW	IVA HOURS	EVA HOURS	# ATTACHED PAYLOADS		# FF SERVICING	# TRANS-PORTATION EVENTS
						# PORTS	# PRES-SURIZED MODULES		
1991	35,900	195	55	12,300	830	6/2	4(2)[2]	3	--
1992	49,900	195	60	12,900	1,450	13/3	4(2)	3	--
1993[1]	55,000	215	63	16,600	1,520	12/4	5(3)	3	--
1994	61,000	275	88	24,800	1,330	11/4	8(5)	2	4
1995	101,000	275	101	25,200	230	7/4	11(8)	2	6
1996[1]	107,000	310	106	29,500	160	10/4	14(10)	2	12
1997	101,000	305	121	30,200	150	8/4	14(10)	1	10
1998	99,000	305	112	27,400	140	5/4	14(10)	2	13
1999[1]	96,000	370	130	27,500	110	2/2	15(10)	2	14
2000	94,000	365	129	26,900	70	2/2	15(10)	2	14

(1) EEG PRODUCTION FACILITY ADDITIONAL UNITS BROUGHT ON LINE IN 1993, 1996, AND 1999 ARE ASSUMED TO BE CO-ORBITING FREE FLYERS

(2) NUMBER IN PARENTHESIS IS THE NUMBER OF COMMERCIAL PRODUCTION UNITS PROVIDED BY INDUSTRY

6.4.2 Co-Orbiting 28.5° Platform

The summary requirements for the co-orbiting 28.5° platform are given in Figure 6-5. These requirements are associated with U.S. science payloads. As noted in the results of the parallel international utilization studies, accommodation of international instruments, while not shown in this figure, is clearly a possibility. The number of servicings per year indicated in Figure 6-5 is based on the need for payload interchange and servicings and require use of the OMV to either bring the platform to the proximity of the manned Station or to transport the payload to the platform for exchange.

6.5 INTERNATIONAL SPACE UTILIZATION

Parallel studies of space utilization have been undertaken by the international community. These initial studies have been completed recently and are summarized here only in broad terms. Additional information was provided in an international panel discussion at the symposium. ESA, Japanese, and Canadian results are summarized in Table 6-1 and compared with U.S. use in Table 6-2. As noted, a manned R&D lab for materials science and space processing is required from the viewpoint of all countries. Fundamentally, all the countries note a substantial role for a manned Space Station in both science and applications and technology development. Operational support to unmanned facilities is also viewed as a major Space Station role.

Although U.S. requirements for the low inclination platform are relatively modest, the international community also sees a need for such a platform for astronomical observations. Japan sees a need for a manned facility at high inclination primarily to support real-time oceanographic applications. Although the U.S. is the only country calling for an attached MPS processing facility, the German Colombus Study focuses on a Spacelab derivative system which can operate in an attached or co-orbiting mode.

FIGURE 6-5

SUMMARY REQUIREMENTS FOR A 28.5° CO-ORBITING PLATFORM

YEAR	POWER KW	RECORDING DATA RATE MBPS	# ATTACHED PAYLOADS	PAYLOAD MASS KG	# SERVICINGS
1991	2.5	16	2	6,400	2
1992	3.1	66	3	11,500	3
1993	4.7	67	4	18,500	2
1994	1.9	50	2	12,400	3
1995	3.2	51	3	19,400	2
1996	3.3	51	2	16,600	3
1997	2.6	2	3	16,600	3
1998	2.6	2	3	16,600	2
1999	4.9	44	3	25,500	3
2000	2.6	42	1	12,500	2

TABLE 6-1
INTERNATIONAL SPACE UTILIZATION

ESA (128 Payloads)	JAPAN	CANADA (37 Payloads)
MATERIAL SCIENCE AND SPACE PROCESSING - AUTOMATED PROCESSING FACILITY (20 KW) - MANNED R&D FACILITY (10 KW) LIFE SCIENCES - FREE FLYER (EURECA) - MANNED R&D FACILITIES (SHORT AND LONG MODULES) SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, FREE FLYERS, AND PLATFORM (57 DEGREES TO POLAR) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS, AND PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - ASSEMBLY/CONSTRUCTION - SATELLITE SERVICING NEW FIELDS - CALIBRATION LAB - MODULAR OTV - SOLAR ENERGY TRANSMISSION - SPACE PROPULSION SYSTEM DEVELOPMENT - SPACE DEBRIS REMOVAL	MATERIAL SCIENCE AND SPACE PROCESSING - MANNED R&D FACILITY - PROCESSING FACILITY LIFE SCIENCES - MANNED R&D FACILITY (BIOLOGY, SPACE MEDICINE, CELSS) SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, MANNED AND UNMANNED FACILITIES (NEAR POLAR) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS/ PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - FREE FLYER FOR SPACE PLASMA, ADVANCED PROPULSION, MICROWAVE ENERGY TRANS-MISSION, SOLAR ARRAYS AND CONCENTRATORS - ATTACHED MODULE FOR LARGE STRUCTURES, LONG DURATION EXPOSURE, ZERO GRAVITY LIQUID HANDLING COMMUNICATION TECHNOLOGY - LARGE ANTENNAS CONSTRUCTION - SATELLITE ASSEMBLY AND TEST - MAINTENANCE	MATERIAL SCIENCE AND SPACE PROCESSING - MANNED R&D FACILITY - AUTOMATED PROCESSING FACILITY LIFE SCIENCES - MANNED R&D FACILITY SPACE SCIENCES AND APPLICATIONS - EARTH OBSERVATIONS, FREE FLYERS/ PLATFORM (SUN SYNCHRONOUS, 4-7 KW, 120-240 MBPS) - ASTRONOMICAL OBSERVATIONS, FREE FLYERS/ PLATFORM (LOW AND HIGH INCLINATION) TECHNOLOGY AND OPERATIONS - LARGE STRUCTURES CONSTRUCTION/ASSEMBLY - SOLAR CELLS/ARRAYS - SENSOR DEVELOPMENT - OTV SRM - MAINTENANCE, SERVICE, REPAIR

TABLE 6-2

INTERNATIONAL SPACE UTILIZATION SUMMARY

MISSION AREA	U.S.	ESA	JAPAN	CANADA
MATERIAL SCIENCE AND SPACE PROCESSING				
MANNED R&D LAB	●	●	●	●
ATTACHED PROCESSING FACILITY	●			
CO–ORBITING PROCESSING FACILITY	●	●	●	●
LIFE SCIENCE				
MANNED R&D LAB	●	●	●	●
CO–ORBITING RES. FACILITY				
SPACE SCIENCES AND APPLICATIONS				
EARTH OBSERVATION				
HIGH INCL. FF/P	●	●		●
ATTACHED RES.	●			
MANNED HIGH INCL.			●	
ASTRONOMICAL OBSERVATION				
ATTACHED OBS.	●			
LOW INCL. FF/P	●	●	●	●
HIGH INCL. FF/P	●	●	●	●
TECHNOLOGY AND OPERATIONS				
LARGE STRUCTURES	●	●	●	●
ENERGETICS	●	●	●	●
SENSOR DEVELOPMENT	●			●
MAINTENANCE/SERVICE/REPAIR	●	●	●	●
OTV	●	●		●

6.6 SPECIAL REQUIREMENTS

Each mission area has its own special requirements that will impact the Space Station design. Science and applications missions, whether Earth observations or astronomical, require stringent control of the contamination environment around the Space Station. These requirements are defined in more detail for representative instruments in the Mission Requirements Workshop (Langley) report. These missions also require highly accurate pointing and stability.

Commercial missions may require physical and communications security for proprietary processes and/or experiments. Rapid replacement of DBS satellites in geosynchronous orbit requires the capability for on-orbit storage of complete spacecraft. Finally, the materials processing facilities require storage of raw materials and spare equipment.

Technology development missions are unique in their requirement for large amounts of EVA time. A corolary to this requirement is the need for improved suits, tools, and techniques to maximize man's productivity in extravehicular activities.

7.0 POTENTIAL SPACE STATION BENEFITS

7.1 SUMMARY

The Space Station Mission Analysis Studies, the concurrent Mission Requirements Working Group and panel activities, and the culminating Space Station Mission Requirements Workshop have all contributed to a better understanding of potential Space Station benefits. Just as the Space Station supports a diverse set of mission activities, the benefits occur in many diverse ways. It does not appear that there is one benefit that clearly justifies a Space Station. However, the cumulative payoff of the potential benefits accrued in different aspects of such a program does create a compelling case for a Space Station. The potential benefits are summarized in four general categories:

(1) Mission enablement and enhancement due to extensive manned presence;

(2) Creation of a viable commercial activity, particularly in space materials processing;

(3) Significant cost savings due to more efficient transportation and servicing operations; and

(4) Tangible and intangible societal benefits related to mission results, space R&D applications, and national prestige.

7.2 MISSION ENABLEMENT AND ENHANCEMENT

The workshop report identified three types of new activities enabled by the Space Station: (1) Long-duration life science missions, (2) materials processing experiments, and (3) planetary sample return. The focus of life sciences would be the study of the effect of gravity and weightlessness in several species of plants and animals including, of course, humans. For materials processing, the Space Station provides long duration, controlled low-gravity levels in a manned laboratory environment. The transportation mode function of a Space Station would enable missions such as the planetary sample return which requires initial mission mass far in excess of a single Shuttle launch capability.

Mission enhancement may be realized in many different ways. For many missions, manned presence provides benefits related to maintenance and repair, real time mission involvement, automation of difficult laboratory operations, and construction, assembly, and checkout of large systems. Payload servicing to extend mission lifetimes is of special interest to science observations desiring long-term data and allows the accumulation of science assets rather than requiring replacement of assets with limited life. Cost benefit assessments have been conducted on several missions comparing costs with and without a Space Station. In one set of such assessments, the Space Station showed cost benefits of 20 to 40 percent. In comparison with Space Lab missions, mission hardware does not have to be relaunched for each cycle of experiments.

7.3 COMMERCIAL MISSIONS

The Mission Analysis Studies have revealed a surprisingly large, latent commercial interest in materials processing. However, without a Space Station most of the potential opportunities would not be explored or the rate of development would be severely inhibited. A materials processing R&D facility and pilot plant facilities for biological, containerless, and furnace processing require longer, man-tended durations than are available on the Shuttle to demonstrate the viability of commercial materials space processing. Also, because of the infant nature of this industry, the government must encourage the private sector by providing facilities, basic science research, technology development and demonstration, and by reducing the technical and institutional barriers to utilization of space.

7.4 COST SAVINGS DUE TO MORE EFFICIENT SPACE OPERATIONS

Many areas have been identified where a Space Station can contribute to more efficient space operations, particularly with regard to utilization of the Space Transportation System (STS), with the resulting potential for major cost savings. The availability of a Space Station can reduce the number of Shuttle flights required to service the mission model by approximately 20 percent as a result of increasing the average Shuttle load factor, reducing required on-orbit stay time, and off-loading of certain missions such as satellite servicing. In addition to reduction of numbers of flights, the Shuttle fleet size requirements are possibly reduced by over 30 percent. The total impact has been estimated to result in an approximate 50 percent improvement in the Shuttle fleet productivity.

Use of the Space Station as a transportation node to support Orbital Transfer Vehicle (OTV) and Teleoperator Maneuvering System (TMS) operations is a particularly powerful case. Mixed manifesting and scavenging of propellants provides powerful productivity and cost gains while TMS operation relieves the Shuttle of flights dedicated to orbital servicing. The ultimate case of the transportation node is that of space-based OTVs and TMSs giving the highest potential level of operational flexibility and efficiency.

7.5 SOCIETAL BENEFITS

Benefits in this category fall into tangible, potentially quantifiable areas and into intangible, more qualitative areas. Tangible benefits relate to the impacts of Space Station missions on understanding of the Earth's environment (one study report referred to these as trillion dollar issues), understanding of our solar system and universe, quality of life enhancements due to science and technology advances in life sciences and materials processing, and improved economy due to new high technology commercial ventures and products.

And finally, though certainly not last in importance, is the impact of such a program on national prestige. The value of maintaining the leadership role of the United States in space activities is high in terms of international competition and potential international cooperation. The space program has served as a focus for national pride and could continue to do so with an imaginative and aggressive Space Station program.

APPENDIX A

MISSION DESCRIPTION DOCUMENT

LIST OF ACROYNMS

APPENDIX A

LIST OF ACRONYMS

AAC	Advanced Adaptive Control
ACD	Attitude Control Development
ACD	Advanced Control Devices
ACG	Atmospheric Composition Payload Group
ADG	Atmospheric Dynamic Payload Group
AEPI	Space Plasma Physics Low Light TV
ALT	Radar Altimeter
ASO	Advanced Solar Observatory
ATMOS	Atmospheric Trace Molecules Spectrometer
AVHRR	Advanced Very High Resolution Radiometer
AXAF	Advanced X-Ray Astronomical Facility
AXET	Space Plasma Physics X-Ray Telescope
BHFT	Basic Human Factor Technology
BP	Biological Processing
BPM	Biological Production Module
C^3	Command, Control, and Communication
CAP	Controlled Acceleration Propulsion
CDG	Concept Development Group
CDM	Corona Diagnostic Mission
CELSS	Closed Environmental Life Support System
CFS	Cryogenic Fluid Storage
CFT	Crew Factors Technology Group
CG	Crystal Growth
CGSP	Crystal Growth and Solidification Processes

CM	Centimeter
CMG	Cryosphere Monitoring Payload Group
CML	Commercial MPS Lab
COMF	Combustion Facility
CONT	Contamination Technology
CP	Containerless Processing
CRM	Chemical Release Module
CRY	Cryogenics
CTMS	Commercial Teleoperator Maneuvering System
CWFS	Wind Field Scatterometer
DBS	Direct Broadcast Satellites
DCLS	Data Collection and Location System
DROP	Liquid Droplet Radiator
DSCG	Directional Solidification Crystal Growth
ECG	Electroepitaxial Crystal Growth
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Mobility Unit
EOS	Electrophoresis Operations in Space
EOSD	Earth Observations Sensor Development Laboratory
ESA	European Space Agency
ESR	Earth Science Research
EVA	Extravehicular Activity
FBT	Feedback Technology
FCP	Fluid and Chemical Processing
FLD	Fluid Dynamics
FMT	Fluid Management Technology Group

FST	Fire Safety Technology
FTS	Fourier Transform Spectrometer
FUSE	Far Ultraviolet Spectroscopy Explorer
GEO	Geosynchronous Earth Orbit
GEOS	Geodynamic Experimental Ocean Satellite
GeV	Giga-electron Volts
GLSC	Government Launch Services (Cryogenic)
GLSS	Government Launch Services (Storable)
GMS	Geostationary Meteorological Satellite
GRE	Gravitational Redshift Experiment
GRM	Geopotential Research Mission
GRO	Gamma Ray Observatory
GSLA	Government Large Structures Assembly
GSSF	Government Satellite Services Facility
HABT	Habitability Technology
HEIE	High Energy Isotope Experiment
HEO	High Earth Orbit
HLAG	High Inclination Low Energy Astronomy Payload Group
HMF	Health Management Facility
HRS	High Resolution X-Ray and Gamma-Ray Spectrometer
HTM	High Throughput Mission
HVPI	Hi Voltage Plasma Interaction
IEF	Isoelectric Focussing
ILSA	Industry Large Structures Assembly
ILSC	Industry Launch Services (Cryogenic)
ILSS	Industry Launch Services (Storable)
IOC	Initial Operational Capability

IRL	IR Lidar
IS	Imaging Spectrometer
ISO	Space Plasma Physics UV and Visible
ISSF	Industry Satellite Services Facility
IUS	Interim Upper Stage
IVA	Intravehicular Activity
JEA	Joint Endeavor Agreement
JSC	Lyndon B. Johnson Space Center (NASA)
KeV	Kilo-electron Volt
KSC	John F. Kennedy Space Center (NASA)
KW	Killowatts
LACO	Laser Communications
LAMAR	Large Area Modular Array
LAP	Leased Attached Pallet
LARS	Lower Atmosphere Research Satellite
LASMMR	Large Aperture Scanning Mutli-frequency Microwave Radiometer
LD	Luminescence Detector
LDEF	Long Duration Exposure Facility
LDR	Large Deployable Reflector
LEEC	Laser to Electric Energy Conversion
LEO	Low Earth Orbit
LeRc	Lewis Research Center (NASA)
LGMT	Low-G Materials Technology Group
LHAG	Low Inclination High Energy Astronomy Payload Group
LIDAR	Light Radar (Meteorological Instrument)
LLAG	Low Inclination Low Energy Astronomy Payload Group
LPT	Laser Propulsion Test

LSB	Leased Spacecraft Bus
LSC	Large Solar Concentration
LRS	Laser Reflectance Spectrometer
LST	Large Structure Technology Group
LSTE	Large Structures Technology Experiment
LTD	Large Space Antenna Technology Development
M^3	Cubic Meters
MAC	Materials and Coatings
MDAC	McDonnell Douglas Corporation
MDD	Mission Description Document
METSAT	Meteorological Satellite
MeV	Mega-electron Volts
MGP	Micro-G Physics and Chemistry Experiments Group
MHAC	Multi-frequency High-Gain Antenna Configuration
MHD	Magneto Heterdynamics
MLA	Multi-spectral Thermal Infrared Imager
MMU	Manned Maneuvering Units
MP	Space Plasma Physics Multiprobes
MPC	Multiple Payload Carrier
MPE	Materials Performance Technology Group
MPF	MPS Products Facility
MPS	Materials Processing in Space
MPTL	Material Processing Technology Laboratory
MRWG	Mission Requirements Working Group
MSAR	Mzulti-frequency, multi-polarization, multi-lookangle, Synthetic Aperture Radar
MSFC	Marshall Space Flight Center (NASA)

MTCT	Manipulator/Teleoperator Control Technology
MTIRI	Multi-spectral Thermal Infrared Imager
NOAA	National Oceanic and Atmospheric Administration
OAST	Office of Astronautic and Space Technology
OCI	Ocean Color Imager
OMG	Ocean Monitoring Payload Group
OMP	Ocean Microwave Package
OPEN	Origin of Plasma in Earth Neighborhood
OSSA	Office of Space Science and Applications
OST	OTV Servicing Technology
OTV	Orbital Transfer Vehicle
OVLBI	Orbiting Very Long Baseline Interferometry
PACE	Physics and Chemistry Experiments
PMS	Polar Meteorological Satellite
POF	Pinhole Occulter Facility
POV	Proximity Operation Vehicle
PPL	Plant Physiology Laboratory
PPPL	Planetary Physical Processes Laboratory
PSS	Polar Subsurface Sounder
PST	Planetary Spectroscopy Telescope
R&D	Research and Development
RFP	Request for Proposal
RMS	Remote Manipulator System
ROTV	Reusable Orbital Transfer Vehicle
RPDP	Recoverable Space Plasma Physics Sub-Satellite
RPL	Rodent and Primate Laboratory
RRG	Earth Resources Payload Group

SAB	Space Applications Board
SADOT	Structures Assembly, Deployment, and Operations Technology
SAR	Synthetic Aperature Radar
SC	Solar Concentrator Group
SCAT	Scatterometer
SCB	Space Science Board
SCDM	Solar Corona Diagnostic Mission
SCL	Space Component Lifetime
SCM	Spacecraft Materials
SCRN	Energy Spectra of Cosmic Ray Nuclei
SDL	Sensor Development Lab Group
SDLT	Static/Dynamic Load Technology
SEPAC	Space Plasma Physics Particle Injection
SET	Servicing Technology Group
SI	Stereo Imaging
SIDM	Solar Internal Dynamics Mission
SIRTF	Shuttle Infrared Telescope Facility
SL	STARLAB
SLA	Scanning Laser Altimeter
SM	Space Plasma Physics Solar Monitor
SMM	Solar Maximum Mission
SOT	Solar Optical Telescope
SOT	Structural Operations Technology Group
SPC	Space Polymer Chemistry
SPL	Solar Pumped Laser
SPLF	Station/Platform Lidar Facility

SPP	Solar Pumped Plasma
SPPG	Space Plasma Physics Payload Group
SPS	Solar Pointing Structure Group
SPT	Solar Panel Technology
SSAR	Stereo Synthetic Aperture Radar
SSE	Solar System Exploration
SST	Satellite Servicing Technology
ST	Space Telescope
STO	Solar Terrestrial Observatory
STS	Space Transportation System
TBD	To Be Determined
TD	Technology Development
TeV	Tera-electron Volts
TMS	Teleoperator Maneuvering System
TOPEX	Topography Experiment
TRIC	Transition Radiation and Ionization Calorimeter
TSC	Thermal Shape Control
UARS	Upper Atmosphere Research Satellite
USRA	United States Research Association
UV	Ultraviolet
VCG	Vapor Crystal Growth
VLBI	Very Long Baseline Interferometer
WISP	Space Plasma Physics Wave Injection
WS	Windsat
XTE	X-Ray Timing Explorer
ZAR	Zero-G Antenna Range

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SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 3

SYSTEM REQUIREMENTS AND CHARACTERISTICS

Prepared By The:
SPACE STATION TASK FORCE

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FINAL EDITION

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SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 3

SYSTEM REQUIREMENTS AND CHARACTERISTICS

Approved By:

JOHN D. HODGE
Director
Space Station Task Force

PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
BOOK 6	SYSTEM OPERATIONS
BOOK 7	PROGRAM PLAN

SPACE STATION SYSTEM REQUIREMENTS DOCUMENT

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1.0 INTRODUCTION

1.1 PURPOSE

This document defines a set of technical requirements for a manned Earth orbiting Space Station and supporting ground systems as compiled by the Concept Development Group. It will serve as a reference document for establishing the top-level program requirements and for use in the definition and preliminary design phases of the Program.

1.2 SCOPE

The Space Station system requirements defined herein are for a permanent, manned low earth orbiting facility and ground assets that will operate with other complementary space systems to support a variety of missions.

This includes the definition of characteristics and requirements for the overall system, subsystems, flight and ground operations, performance, and system verification/acceptance.

1.3 APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this document to the extent specified herein.

- NASA Reference Publication 1024; <u>Anthropometric Source Book</u>, Volume I.
- NHB 5300.4 (<u>TBD</u>), <u>Quality Assurance Requirements</u>.
- NHB 1700.7.
- NHB 8060.B, "<u>Maximum Allowable Concentrations of Toxic Gases</u>."
- JSC 08060.
- International Organization for Standardization ISO/TC 108/SC4N, "<u>Guide to Human Exposure to Whole Body Vibration</u>."
- ISO 2631-1974.
- MSFC Std. 512A.

- JSC-10615, "EVA Designs and Standards."
- NASA/MSFC Document TMX-82473, Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1982 Revision.
- NASA/MSFC Document TM X-82478; Space and Planetary Environment Criteria Guidelines For Use in Space Vehicle Development, 1982 Revision, Volume I.
- TBD NASA Document; Space Debris Prediction Model.
- TBD NASA Document; Factor of Safety Criteria.
- TBD NASA Document; Fracture Control Requirements.
- NASA/JSC 07700, Volume XIV, Space Station System Payload Accommodations.
- TBD NASA Document; Materials Requirements.
- NASA/JSC 07700, Space Shuttle Program Description and Requirements Baseline.

2.0 SYSTEM DEFINITION

The Space Station System is comprised of both manned and unmanned Earth-orbiting, interdependent elements. The purpose of this system will be to operate and maintain payloads, experiments, and facilities attached to a manned core, mounted on platforms, or flown as free-flyers. Operation and maintenance will be provided for commercial missions, science and applications missions, and technology development missions.

2.1 ELEMENTS

The Space Station System is a network of space and ground assets which work together to support a variety of missions.

The elements of the Space Station System are:

- Space Station Base;
- Space Platforms;
- Free Flyers;
- Teleoperator Maneuvering System (TMS);
- Orbital Transfer Vehicles (OTV);
- Orbiter Berthing Equipment; and
- Ground Support Equipment and Facilities.

(Requirements for free flyers, TMS and OTV are described in other programmatic documents.)

The Space Station Base provides the following capabilities:

- Assembly and Berthing;
- Living Quarters;
- Operations (Laboratories);

- Utilities;
- Logistics;
- Remote Manipulator System (RMS); and
- Servicing Capability.

The Space Platforms include:

- Co-orbiting 28.5° Platform; and
- Polar Platform.

The elements of the OTV Facility include:

- OTV;
- Servicing Capability;
- OTV Hangar; and
- OTV Propellant Storage Tank.

A partitioning of functions and capabilities among a reference complement of basic Space Station elements is provided for reference in Appendix C.

2.1.1 Assembly and Berthing

The assembly and berthing capability provides the coupling device through which the Space Station modules are interconnected. Additionally, it provides an airlock and the facilities to store, service, and repair TBD spacesuits. It may also provide control consoles for RMS, TMS, and OTV operations (subject to the constraint that these consoles be located so as to afford optimum direct viewing of the operations).

2.1.2 Living Quarters

The living quarters will provide private crew quarters, a wardroom and a galley, and will satisfy the principal health and recreational needs of the crew.

2.1.3 Operations

The operations capability (laboratories) will accommodate research in a pressurized environment with possible continuous manned interaction. External attachments to which unpressurized payloads may be connected will be provided.

2.1.4 Utilities

Electrical power, thermal control, data processing, communications, attitude control, and orbit maintenance will be provided to the Space Station Base.

2.1.5 Logistics

A capability to resupply the Space Station Base with all required consumable items will be provided. It will also contain the crew primary hygiene facilities. Furthermore, provision will be made for processed materials and trash to be returned to the ground.

2.1.6 Teleoperator Maneuvering System (TMS)

The TMS will be a general-purpose, remotely controlled, free-flying vehicle. It will be controlled, refueled, and otherwise serviced at the Base. Its capabilities will include deploying, retrieving, reboosting, and maneuvering of satellites.

2.1.7 Remote Manipulator System (RMS)

The Space Station RMS is a relocatable, multi-segment device. This Space Station RMS is capable of reaching, grappling, lifting, moving, stowing, and berthing objects. The RMS on the Space Station is expected to be similar to the RMS used on the Shuttle.

2.1.8 Servicing Capability

The Servicing Capability will be comprised of a structure which will provide attachment facilities and hangars at which satellites and the Teleoperator

Maneuvering System will be serviced, refueled, and stored. It will have tankage to store propellants for satellite and TMS refueling. It will also support the mating and checkout of payloads with upper stage vehicles. As the Space Station evolves, the Servicing Capability will provide OTV Hangars and OTV Propellant Storage Tank(s), support the operations of the TMS's and OTV's, and support the assembly of large, complex structures.

2.1.9 Orbital Transfer Vehicle (OTV)

The OTV is a propulsive vehicle that will have the capability to boost payloads from low Earth orbit to geosynchronous and other high energy orbits, including orbits of different inclinations. The OTV will be reuseable and based in space at the Space Station Base where essentially all maintenance, refueling, and checkout of the vehicle will be performed. (Capability to return the OTV to the ground for major overhaul or refitting will be maintained).

2.1.10 OTV Hangar

The OTV Hangar is an unpressurized structure inside of which the OTV will be serviced and stored for micrometeroid and debris protection.

2.1.11 OTV Propellant Storage Tank

The OTV Propellant Storage Tank will contain tanks for propellants, pressurants, and other fluids to be used by the Orbital Transfer Vehicle (OTV). This Propellant Storage Tank will be accessible to the Servicing Capability.

2.1.12 Orbiter Berthing Equipment

Berthing of the Shuttle Orbiter with the Space Station Base, and the resulting transfer of crew and materials in a pressurized environment, will be accomplished through the Orbiter Berthing Equipment.

2.1.13 Ground Support Equipment And Facilities

The Ground Support Equipment and Facilities consists of the equipment required to: integrate, checkout, service, handle, and transport the Space Station elements prior to launch; monitor the health and status of the Space Station during mission and orbital operations; re-service and maintain returned Space Station elements; and provide an interface between the customer and the Space Station during all operational phases.

2.1.14 Space Platform

The Platform is an unmanned spacecraft which will provide power, thermal control, data transmission, attitude control, and orbit maintenance for a complement of payloads. The design of the Platform is derived from the Utility Module. The Platform will allow payloads to be serviced, removed, or replaced on-orbit. Platforms will be capable of flight in low Earth orbit in inclinations from approximately 28.5° (co-orbiting with the Station Base) to polar/sun-synchronous.

(The term "co-orbiting" platform refers to a platform whose orbit permits convenient accessibility with the manned core at a frequency of TBD days).

2.1.15 Free Flyers

Free flyers are spacecraft with a specific mission. The Space Station Base will have the capability to communicate with, service, refuel, and repair free flyers.

2.2 CAPABILITY EVOLUTION

There will be four phases in the Space Station System configuration evolution: Initial Operational Capability (IOC), Phase II, Phase III, and Phase IV.

2.2.1 IOC Capability

2.2.1.1 Orbit

The Space Station Base will orbit at an inclination of 28.5 degrees and with an altitude of TBD nautical miles.

2.2.1.2 Crew Size And Living Quarters

The IOC Space Station will have a crew of TBD persons and living quarters volume of TBD cubic feet.

2.2.1.3 Power And Thermal Capabilities

The IOC Space Station Base will have the capability to provide 75 Kilowatts of continuous electrical power -- TBD Kilowatts of power for the customers and TBD Kilowatts of power for Station needs. Appropriate heat rejection capability for this 75 kilowatts average power will be provided.

2.2.1.4 Laboratory And Payload Capabilities

The IOC Space Station Base will have TBD cubic feet within the Operations Modules of pressurized laboratory volume. It will also provide TBD external attachments to which unpressurized payloads may be attached. Of those unpressurized attachments, TBD attachments will have rotational capabilities (TBD degrees of freedom) for pointing of payloads. There will also be TBD ports with pressurized hatches which can accommodate pressurized payloads.

2.2.1.5 Servicing Capabilities

The IOC Space Station Base will have a Servicing Capability to support the servicing of payloads attached to the Station Base, to support the storage and servicing of the Teleoperator Maneuvering System (TMS), to support the return, servicing, and redeployment of co-orbiting satellites, and to support the servicing of the 28.5° space platform and its payloads.

2.2.1.6 Space Platforms

Two unmanned Space Platforms will be provided at IOC. One platform will be in near-polar orbit and will supply TBD Kilowatts of power. The other platform will be in 28.5 degree orbit and will provide TBD Kilowatts of power.

2.2.2 Phase II: Capability Evolution

The Phase II Space Station System will have all the capabilities of the IOC Space Station System. In addition, it will have the below-listed capabilities.

2.2.2.1 Crew Size And Living Quarters

The Phase II Space Station Base will have a crew of TBD persons and a living quarters volume of TBD cubic feet (an increase of TBD persons and TBD cubic feet of living quarters volume beyond the IOC capabilities).

2.2.2.2 Power And Thermal Capabilities

The Phase II Space Station Base will have the capability to provide 150 kW of continuous electrical power, TBD kW of power for station needs and TBD kW of power for customers. Appropriate heat rejection capability for this 150 kW average power will be provided.

2.2.2.3 Laboratory And Payload Capabilities

The Phase II Space Station Base will have TBD cubic feet within the Operations Modules of pressurized laboratory volume. It will also provide TBD unpressurized ports to which unpressurized payloads may be attached. Of those unpressurized ports, TBD ports will have rotational capabilities (TBD degrees of freedom) for pointing of payloads. There will also be TBD ports with pressurized hatches which can accommodate pressurized payloads.

2.2.2.4 Servicing Capabilities

The Phase II Space Station Base will have a TBD servicing facility (expanded TBD beyond the IOC capability) to support the storage and servicing of TBD TMS's; the return and servicing of co-orbiting satellites; the assembly, checkout, and launch to geosynchronous and other high energy orbits of payloads mated to expendable upper stages; and the servicing and support Technology Development missions.

2.2.3 Phase III: Capability Evolution

The Phase III Space Station System will have all the capabilities of the Phase II Space Station System. In addition, it will have the below-listed capabilities.

2.2.3.1 Crew Size And Living Quarters

The Phase III Space Station Base will have a crew of TBD persons and living quarters volume of TBD cubic feet (an increase of TBD persons and TBD cubic feet of living quarters volume beyond the Phase II capabilities).

2.2.3.2. Servicing Capabilities, Orbital Transfer Vehicle, And Facilities

The Phase III Space Station Base will have a TBD servicing facility (expanded TBD beyond the Phase II capability) to support the additional functions of service and launch of a space-based, reuseable Orbital Transfer Vehicle (OTV). It will support the assembly and checkout of payloads mated to the OTV (including mating of a TMS for missions to provide in-situ servicing to satellites at geosynchronous and other high energy orbits). It will also have a hangar facility and an OTV Propellant Storage Tank.

2.2.4 Phase IV: Full Growth Space Station

The Growth Space Station System will have all the capabilities of the Phase III Space Station System. In addition, it will have the below-listed capabilities.

2.2.4.1 Crew Size And Living Quarters

The Growth Space Station Base will have a crew of TBD persons and a living quarters volume of TBD cubic feet (an increase of TBD persons and TBD cubic feet of living quarters volume beyond the Phase III capabilities).

2.2.4.2 Orbital Transfer Vehicle And Facilities

The Growth Space Station Base will service two Orbital Transfer Vehicles (OTV's). It will also have two hangar facilities for those OTV's and OTV Propellant Storage Tanks.

2.2.4.3 Laboratory And Payload Capabilities

The Growth Space Station Base will have TBD cubic feet within the Operations of pressurized laboratory volume. It will also provide TBD unpressurized ports to which unpressurized payloads may be attached. Of those unpressurized ports, TBD ports will have rotational capabilities (TBD degrees of freedom) for pointing of payloads. There will also be TBD ports with pressurized hatches which can accommodate pressurized payloads.

3.0 CUSTOMER ACCOMMODATIONS

The Space Station will provide the following customer accommodations based on the mission requirements described in the Space Station Mission Requirements Report, (month), (year).

3.1 ORBITAL AND VIEWING PARAMETERS

The elements of the Space Station System will be placed in the following orbits:

	Inclination (degrees)	Altitude (n. mi.)
Base	28.5	TBD
Co-orbiting Platform	28.5	TBD
Polar Platform	TBD	TBD

The Space Station will simultaneously accommodate instruments that have the following viewing requirements: Earth, anti-Earth, solar, and stellar.

3.2 POINTING ACCURACY AND STABILITY

The pointing accuracy and stability of each element will be as follows:

	Accuracy (degrees)	Stability (degree/second)
Base	TBD	TBD
Co-orbiting Platform	TBD	TBD
Polar Platform	TBD	TBD

3.3 RESOURCES

Resources as described in the following paragraphs will be provided to the customers by the Space Station.

3.3.1 Power

The quantity of power continually provided by each element will be as follows:

	Phase I	Phase II	Phase III	Phase IV
Base	TBD	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD	TBD

The type of power (ac/dc, voltage level, etc.) will be TBD.

3.3.2 Thermal Control

The Space Station will provide heat-rejection capability of TBD kW at TBD°F ± TBD °F. The quantity provided by each element will be as follows:

	Phase I	Phase II	Phase III	Phase IV
Base	TBD	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD	TBD

3.3.3 Telemetry, Command, And Timing

Telemetry from the customers' equipment will be handled by the telemetry system element of the data management system. Commands from customers can be generated at any of the following locations: (1) The customer facility (on the ground); (2) the Space Station Ground Control Center; and (3) the Space Station. Stored commands will be generated based on inputs from the user only in the Space Station Ground Control Center; they will then be stored in the Space Station data handling system for forwarding to the customer system at the execution time tag of the command. A clock will be available to the customer for time-tagging customer data.

3.3.4 On-Board Data Management

The Space Station elements will provide the following total data rate capability to the customers:

Data Rate Capability - MBPS

	Phase I	Phase II	Phase III	Phase IV
Base	TBD	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD	TBD

The Space Station elements will have the following data rate capabilities:

(1) The base and both platforms will transmit customer data to the ground (through TDRSS) at a bit error rate of 1×10^{-5} or better.

(2) The co-orbiting platform will transmit data from the customer system on the platform to the Base at a maximum data rate of TBD bps.

(3) A direct to ground transmission link for raw and/or science data will be available with a TBD rate.

The customer data storage capability with a bit error rate of 1×10^{-5} or better for each Space Station element is as follows:

Customer Data Storage Capability - Mbits

	Phase I	Phase II	Phase III	Phase IV
Base	TBD	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD	TBD

3.3.5 Ground Data Management

A planning and scheduling facility will be available to the customer on the ground. The capability for the customer to operate flight equipment in an interactive mode will be provided according to established interfaces. User operations requirements will be accommodated to the extent possible within the total operations capacity and plan.

Data received from the Space Station will be transmitted to the customers facility after a limited amount of processing along with TBD ancillary data. The Space Station ground system will perform some common functions, such as fine altitude computations and conversion of the time tag of the data to GMT, on data to be distributed to customers. Archival storage of the raw data will not be provided by the Space Station or its ground facilities.

3.3.6 Crew

The Space Station Base will provide for TBD crew persons dedicated to mission support activities. The Space Station program will provide Space Station training for payload specialists and guest investigators. Particular mission support skills will be provided by the customer personnel who will be accommodated as a TBD portion of the crew. Both IVA and EVA crew support will be available to customers. EVA crew activities shall include TBD tasks to a maximum of TBD hours per day.

3.3.7 Pressurized Volume

The Space Station Base will provide pressurized volumes to serve as interior laboratory space and will make provisions for TBD customer-supplied volume. The total volume in the Operations Modules to be provided by the Station is as follows:

Phase	Total Pressurized Volume (ft^3)
I	TBD
II	TBD
III	TBD
IV	TBD

3.3.8 Payload Attachments

Provisions for attachments for externally mounted instruments shall be provided on the Base and on the Space Platforms. These attachments will provide electrical, thermal, and data resources to the attached instruments. Some of the attachments will provide (TBD degrees of freedom) rotation capability of ± TBD degrees. The number of rotating and stationary attachments is given below.

	Phase I	Phase II	Phase III	Phase IV
Base	TBD	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD	TBD

3.3.9 On-Orbit Assembly

The Space Station Base will have facilities to support the assembly of large structures beginning in Phase II. This includes an attachment area for the structure to be assembled, a storage area of TBD square feet for the components, a remote manipulator system, and an orbital maneuvering system. Power, limited to TBD kW, and data system interfaces will be available to the payload. Thermal control (passive or active) limited to TBD kW will be provided.

3.4 SERVICING

Scheduled and unscheduled maintenance and servicing of attached instruments, modules, platforms, and free-flyers will be provided. Whether servicing is performed *in situ* or at the base is TBD.

3.4.1 Teleoperator Maneuvering System (TMS)

Co-orbiting free-flyers will be serviced by the TMS based at the Base.

3.4.2 Servicing At The Space Station

Instruments on co-orbiting free-flyers and platforms and instruments externally and internally mounted on the Base will be serviced at the Base. TBD tasks will be considered as routine servicing. Other servicing tasks will be scheduled as needed.

3.4.3 Servicing Of The Platforms

Routine servicing of the platforms will be scheduled at TBD month intervals. Contingency servicing will be performed on a TBD basis. The routine servicing capability will include TBD tasks. Servicing of the co-orbiting platform will be performed by the Space Station. Servicing of the polar platform will be done by STS.

3.4.4 Servicing At Geosynchronous Orbit

The Phase IV Space Station will provide remote, automated servicing at geosynchronous orbit.

3.5 LOGISTICS

3.5.1 General Capability

The Space Station System shall provide logistics support to customers throughout the evolution and operation of the Space Station. This service provides for: 1) the periodic resupply of customer consumables; 2) inventory management of all customer flight items, both hardware and consumables, after delivery to the launch site and until the item is returned post-flight; 3) storage, preparation for transport, and transport of customer equipment between the ground and the Space Station; 4) transportation to and from the Space Station to accommodate detached customer (platform, free flyer, etc.) needs; 5) flight storage and preparation of customer equipment or products awaiting mission use or return to Earth; 6) safeguard for proprietary data and equipment on the ground and on the Station as negotiated with customers, and 7) the transport of customer personnel to and from the Space Station.

3.5.2 General Accommodations

The Space Station provides the following general accommodations to support customer logistics requirements.

a. Nominal resupply frequency: 90 days

b. TMS flight rate: TBD

c. OTV flight rate: TBD

3.5.3 Specific Accommodations

The Space Station shall provide the following specific customer logistics accommodations.

3.5.3.1 Pre-Flight Accommodations

Packing and preparation for flight/ shipment of the payload/experiment, hardware or consumables including entering data into the inventory management system, and installation in the launch vehicle shall be accomplished for the customer. Other pre-flight customer requirements for service shall be negotiated as required.

3.5.3.2 Storage

The Space Station shall provide TBD cu.ft. of internal storage volume within the confines and environment of the Space Station to support on-orbit operations. Capability shall be provided by the Space Station to store customer payload/equipment externally.

3.5.3.3 Launch To Berthing And Re-entry Accommodations

The Space Station shall provide the following accommodations to the customer during the period that the payload is within the resupply vehicle.

The customer resupply shall be constrained to TBD pounds total; TBD cubic feet of internal storage space with an individual package size of TBD on each resupply mission. External storage shall be provided by TBD. Provisions for special storage requirements, e.g., freon storage, helium storage, etc., shall be the responsibility of the customer.

The customer shall be provided a maximum of TBD kilowatts of power during launch, coast, and re-entry modes.

The Space Station shall provide the customer with the following environmental conditions during launch, coast, and berthing. These are: TBD.

3.5.3.4 On-Orbit Repair

The Space Station shall provide the use of the standard tool kit to the customer.

3.5.3.5 Consumables

The Space Station shall provide TBD pounds of attitude control consumables and TBD pounds of reboost consumables per each resupply mission to support the customers' needs for special viewing attitudes and altitudes until the next resupply mission.

3.5.3.6 Constraints

The Space Station shall provide, as Space Station equipment, no liquid/gaseous consumable storage capability beyond that required for station/OMV/OTV operation.

3.5.3.7 Inventory Management

The Space Station shall provide inventory management of customer spares, stored tools, etc.

3.5.3.8 Post-Mission Accommodations

The Space Station Ground Support System shall remove the user's down load from the Logistics Module and remove customer item accounts from the inventory management system.

3.6 INDUCED ENVIRONMENT

3.6.1 Contamination

The Space Station contamination environment will be reflected in the selection, design, location, and operation of the Station and all elements operated in its vicinity such as in the docking deployment and retrieval of other spacecrafts. In order to provide for maximum utilization and flexibility, control of the Space Station environment for scientific studies will be necessary. Therefore, contaminants from internal and external sources must be evaluated and monitored. The Space Station configuration, scientific equipment, instrument locations, and operational concepts shall be incorporated in such a manner to be sensitive to all the possible effects of contamination. The final design configuration of the Space Station shall provide for limiting contamination from all sources. All experiment payloads shall also be designed and grouped for a mission such that they will not contaminate each other or any of the critical Space Station components. The requirements for external environment contaminants shall generally be applicable during quiescent operational periods of the Space Station (i.e., no docking, refueling, firing on orbit vernier rockets for attitude control, no flash evaporator operation or major waste dumping operation). The effects of contaminant effluents is expected to be transient and not preclude or significantly delay programmed scientific experiments. These requirements apply to station zones where sensitive instrumentation will be located or within the field-of-view.

The requirements in Table 3-1 shall not be violated from external contamination during quiescent operational periods of the Space Station.

TABLE 3-1

Parameter	Limits Not To Be Exceeded
Column Densities	10^{11} molecules cm^{-2} for $H_2O + CO_2$ 10^{13} molecules cm^{-2} for $O_2 + N_2$ 10^{10} molecules cm^{-2} for other sources
Background Light Levels	Should not significantly exceed normal background sky brightness from natural occurring sources
Particle Release	Not to exceed 1 particle per orbit greater than 5 microns size per 1×10^{-5} steradian field of view as seen by a 1 meter diameter telescope aperture
Deposition of station generated matter as a result of direct or atmospheric scattering	4×10^{-12} gms/cm^2 sec on a 298°K surface 1×10^{-11} gms/cm^2 sec on a 4°K surface

On orbit monitoring of the induced environment at the Space Station shall be provided. Measurements will be made on a routine basis to ensure that the necessary environment is maintained and to protect a TBD class of payload instruments. Evaluation of the Space Station environment may include monitoring of particulate content, condensibles, humidity, and pressure of ambient air in the vicinity of critical instrumental systems. The following list of measurements shall represent the minimum number needed to ensure documentation of the induced environment at the Space Station and shall be made with sufficient sensitivity to detect the levels of contaminants indicated in Table 3-1.

(1) Molecular column density;

(2) Background spectral intensity from UV to IR;

(3) Particle size and velocity distribution;

(4) Molecular deposition on an ambient surface;

(5) Molecular deposition on a cryogenic surface;

(6) Molecular return flux as a function of species;

(7) Particulate deposition on surfaces; and

(8) Degradation of optical surfaces.

In Table 3-2, the Station elements are listed that will be attached to or operate in the vicinity of the Space Station. All the contaminants expected to evolve from the proximity operation of the Station elements are also listed in the Table. In order to ensure that molecular particulate levels listed in Table 3-1 are not violated during data collection periods, coordination of exhaust effluents from all of the Station elements will be necessary. For scientific data collection from a Station element such as a Space Platform or Payload far removed from the Space Station, contamination monitoring will also be necessary. Techniques used to monitor contaminant levels at the Station elements will be similar to those used for on-orbit monitoring of contaminant levels at the Space Station. The contaminant requirements of the external environment at the Station elements that are used for scientific data collection and operating far removed from the Space Station shall be the same as those for the Space Station as listed in Table 3-1.

TABLE 3-2

External Contamination Sources

Source		Contaminant Type	Environment Description Documentation
A.	Space Station	TBD	
	1. ECLSS		
	2. Auxillary Propulsion		
	3. Outgassing		
	4. Fluid Leaks		
	5. EVA		
	6. Waste Dumps		
	7. Vents		
	8. Cabin Leaks		
	9. Surface Material		
	10. Thermal Control System		
B.	STS	TBD	
C.	OMV	TBD	
D.	OTV	TBD	
E.	Space Platform	TBD	
F.	Payloads	TBD	
G.	Other	TBD	

The control of contamination in the internal environment of the Space Station is of vital importance to the welfare of the crew. Efforts will be made to maintain potential internal contaminants to an acceptable level, referenced to documentation number TBD from previous manned spacecraft missions. Instrument monitoring of all internal contaminants that are considered potentially harmful to the crew will be provided. All internal habitable volumes shall have a control system to provide adequate air circulation and filtration to control air particulate levels to less than 10,000 per cubic feet for particles greater than 0.5 microns in size. A special work area shall be provided with work benches in a laminar flow condition resulting in a particulate level of class 100.

Contamination control must start with the identification of the contaminants and their source. Table 3-3 lists some of the potential internal contaminants and possible sources. A review of pertinent data collected from previous spacecraft missions and other environmental systems such as Skylab, Soyaut, isolated research stations and submarines will serve as a data base to obtain levels of contaminants expected. A TBD limit shall be set for all potential contaminants listed in Table 3-3.

TABLE 3-3

Potential Internal Contaminants and Sources

Contaminant	Source
Liquids	
- Water	Various
- Urine	Crew
- Food Juices	Food Supply
- Unknown	Payload, Space Station Systems Spoiled Food
Gases	
- NH_3	Crew
- CO	Crew
- CH_4	Crew
- Sx	Crew
- Unknown	Payload, Space Station Systems
- Toxics	Unknown

Contaminant	Source
Solids	
- Hair, skin, etc.	Crew
- Metallic particles	Payload, Spacecraft Systems
- Inorganic particles	
- Organic particles	
Organisms	
- Bacteria	Crew, food
- Viruses	
Vibration	Crew, Payload, Space Station Systems
Acoustic Noise	Crew, Payload, Space Station Systems
EMI	Payload, Space Station Systems

TABLE 3-3
(Continued)

Magnetic Fields	External environment, payload, Space Station Systems
Ionizing Radiation Sources	External environment, payload
Light (UV, visible, IR)	External environment, payload, Space Station Systems
Heat	External environment, payload, Space Station Systems
Unknown	EVA equipment and external hardware brought into the internal environment

3.6.2 Acceleration Level

The acceleration level, as a function of frequency, at the modules that require low gravitational levels will be as follows:

	Initial Station	Phase IV Station
Base	TBD	TBD
Co-orbiting Platform	TBD	TBD
Polar Platform	TBD	TBD

4.0 OPERATIONS AND LOGISTICS REQUIREMENTS

4.1 SPACE STATION ORBITAL OPERATIONS

The Space Station System shall be assembled, activated, and grown through the addition of elements to its full capability. It shall be maintained, serviced, and resupplied using the Orbiter as a transport vehicle. It shall maintain and service payloads/experiments, either internally or externally attached to the Space Station; operate, maintain, and service a platform, platform-mounted payload/experiments, or free-flyers; assemble, test, service, deploy, and launch payload/OTV and TMS; and assemble large space structures.

These operations require that the Space Station shall be operated in a manned mode, where continuous subsystem monitoring by either the flight crew or ground shall not be required for normal Space Station operations. However, the capability for the crew to status and monitor all subsystem health and status data shall be provided. Mission planning capabilities shall be provided in order to provide systems maintenance and troubleshooting procedures, tracking of consumables, and repair and replace information. On-board operations capability by scientists or payload experts of payload/experiments shall be provided. Scientific/payload data shall be capable of being recovered with a minimum of ground processing. System/subsystem verification shall be performed with a minimum of crew interaction and shall be capable of being initiated automatically or manually. Subsystem reconfiguration in the event of a failure shall be capable of being performed automatically or with crew concurrence. Near-continuous voice contact, Space Station health and status data, and payload data shall be provided between the Space Station and the mission ground support.

4.2 MISSION GROUND SUPPORT OPERATIONS

The personnel within the Space Station system shall require a minimum of ground support to accomplish the routine operations required to operate and maintain the space station systems. However, planning for critical and contingency situations, such as Space Station assembly, initial system/subsystem activation/verification, beyond those normally encountered during operations requires that an adequate capability be developed to provide support. This support to the flight operation requires that the total system, both flight and ground, provide the following:

a. A capability of a real-time display of Space Station system health and status within the coverage provided by TDRS/TDAS to the ground support team.

b. A capability to support Space Station assembly, system/subsystem activation/verification, maintenance, and mission reconfiguration with data.

c. A capability for near-continuous voice contact between the Space Station and the ground support personnel within the coverage provided by TDRS/TDAS.

d. A capability to provide video, text, and graphics, and uplink commands/data to the Space Station from the ground.

e. An interface between the flight/ground support equipment that requires a minimum of specialized training for the crews to interact to the equipment.

f. An information management system that shall be capable of supporting the Space Station system with maintenance and troubleshooting procedures, recall of critical-mode or contingency procedures within TBD minutes, consumable management data, configuration management data, inventory management support, etc.

g. A capability for long-term mission planning including a trajectory and rendezvous planning service relating to Space Station, TMS, OTV, platforms, and other free flyers.

4.3 GROUND PROCESSING OPERATIONS

4.3.1 General Requirements

The ground processing operations shall verify the interfaces of the Space Station elements and payloads prior to installation and/or use in the Space Station. This verification requires that the ground processing function meet the following requirements:

a. Provide the capability to checkout each interface, electrical, thermal, software, and mechanical, between station elements and payloads.

b. Provide the capability to service and deservice consumables within the elements during the initial processing of the elements and during the resupply function.

c. Provide the capability to troubleshoot and repair returned elements, remove failed components, and install replacements.

d. Provide the capability to ensure that all modifications to the Space Station will function as required.

4.4 TRAINING AND SIMULATION

4.4.1 General Requirements

Training shall be provided to ensure that the flight crew and ground crew are trained in the normal operation of the Space Station and receive specialized training in support of all critical operations and activities.

4.4.2 Training

Training programs shall be developed and conducted for flight crew, ground support crew personnel, and customers consistent with their needs, which shall provide the skills and knowledge needed to operate and maintain Space Station systems and subsystems and to perform routine Station activities and mission operations. Special training shall be provided to deal with Station and/or medical emergencies within the Shuttle rescue capability. An additional training program shall be provided for flight crew family members to manage the aspects of separation, communication, and the on-going relationships involved in flight duty.

4.4.3 Training Facilities

The training program shall provide ground-based and on-orbit facilities to support training. Ground-based facilities shall be provided and may include training facilities and aids such as a one-g trainer, proximity operations trainer, a weightless environment training facility, altitude chambers, and a Space Station system trainer which will include medium fidelity simulators, etc. On-board simulators and video programs shall be provided for training and skill maintenance for use in flight.

4.4.4 Feedback Program

A non-intrusive and interactive feedback program shall be used in cooperation with the crews to assess the effectiveness of systems and procedures, and to compare training and in-flight performance. This data shall become a readily accessible component of the program data base.

4.5 CONTINGENCY OPERATIONS (TBD)

4.6 LOGISTICS

4.6.1 General Capability

The logistics function shall provide support to the Space Station, the payload/experiment, and related Space Station ground equipment during the activation, operation, and growth periods which allows for an efficient, cost-effective operation to be maintained. This function shall provide for: (1) A periodic resupply of all consumables to the Space Station from the launch site; (2) a resultant offload of hardware and products from the Space Station back to the launch site; (3) inventory management of all Space Station items, both flight and ground spares, hardware and consumables required to support the Space Station; (4) identification, development, and procurement of ground repair facilities/methods for Space Station equipment; (5) procurement, ground transportation, and ground storage of Space Station spares and consumables necessary to support activation and operation; and (6) preparation for shipment and storage of hardware at the launch site.

These consumables and hardware may consist of food, clothes, atmospheric replenishment gases/liquid (O_2/N_2), propellants for attitude control, reboost, TMS and OTV, water, raw and processed materials, spare panels, spare parts, special maintenance/servicing equipment, retrofit kits, new experiments, experiment supplies such as film, gases, or any item determined to be necessary for the activation and continued operation of the Space Station or its payload.

4.6.2 General Accommodations

The Space Transportation System shall provide the Space Station system the following specific logistics accommodations to support the mission operations:

a. Nominal Space Station resupply frequency - 90 days; and

b. Orbiting platform resupply/servicing frequency - TBD.

4.6.3 Specific Accommodations

The Space Station shall provide the following specific logistics accommodations.

4.6.3.1 Pre-Flight Accommodations

Packing and preparation for flight, including entering data into the inventory management system of: (1) The customer items provided for in paragraph 3.5.3.2; and (2) those items necessary to support the Space Station operations during the time period covered by a resupply mission.

4.6.3.2 Launch To Berthing And Re-entry Accommodations

The Space Station logistics function shall provide environmental services and power, within the resupply vehicle and under the constraints of the STS, to meet the requirements of paragraph 3.3.3.3 and the requirements of Space Station items being transported to support the operation.

Space Station equipment and payloads to be stored externally to the Space Station shall be transported by TBD.

4.6.3.3 On-Orbit Accommodations

The Space Station shall provide TBD cubic feet of internal storage space to support the requirements of paragraph 3.5.3.2 and contingency Space Station components, repair parts, etc., and the capability to store customer payload/equipment (paragraph 3.5.3.2) externally on the Space Station.

4.6.3.4 Post-Mission Accommodations

The Space Station ground support system shall support the requirements of paragraph 3.5.3.8, remove the Space Station items requiring rework/repair/-cleaning and initiate the necessary logistics action.

4.6.3.5 Transportation Of Modules

The Space Station equipment/elements shall be designed to use the methods and modes of transportation that are or shall be available within the STS inventory when the transportation need exists.

4.7 FACILITIES

Facilities shall be provided for the mission support equipment, ground verification equipment, servicing equipment, spares and consumables, customer interface equipment, and repair equipment.

5.0 SYSTEM REQUIREMENTS

5.1 PERFORMANCE

The following requirements for the Space Station correspond to the station configuration with the full capability or the "growth capability". However, it shall be designed for a systematic build-up starting from an initial operational capability (IOC) to the final full capability.

The Space Station Base, the Space Platforms, and other flight elements shall be compatible with the Shuttle for delivery to orbit, assembly, and disassembly.

5.1.1 Orbit

5.1.1.1 Space Station Base

The Space Station Base shall be designed to be operated between TBD and TBD n.mi. orbital altitude, in near circular orbits with an eccentricity less than TBD, and in an orbital inclination of 28.5°(± TBD).

5.1.1.2 Space Platforms

The Co-orbiting Platform shall be designed to be operated between TBD to TBD n.mi. orbital altitude, in near circular orbits with an eccentricity less than TBD, and in an orbital inclinations of 28.5° (± TBD).

The Polar Platform shall be designed to be operated between TBD to TBD n.mi. orbital altitude, in near circular orbits with an eccentricity less than TBD, and in an orbital inclination that is sun synchronous between TBD and TBD degrees. The platform shall be designed to operate with a local hour angle of the daylight node crossing between TBD to TBD and for either an ascending or descending node.

5.1.1.3 TMS/OTV/Satellite Servicing

The Space Station, utilizing TMS and OTV, shall be capable of deploying free flying satellites to low Earth and geosynchronous orbits (details of delivery capability - TBD) and retrieving free flying satellites and Space Platforms for servicing or bringing down to ground (details TBD).

5.1.2 Natural Environment Design Criteria

The Space Station shall be designed to meet all performance requirements in the natural environmental conditions prescribed in Appendix B.

5.2 SYSTEM LIFETIME

5.2.1 Operational Lifetime

The Space Station Base shall have the ability to remain operational indefinitely through periodic maintenance and replacement of components. To this end, all subsystems shall be designed for modular-growth, on-orbit assembly, disassembly, and replacement and on-orbit repair and maintenance. All subsystems shall have a specified ten year design life minimum requirement using maintenance as necessary.

5.2.2 Safe Disposal

Provisions shall be made for the safe disposal of the Space Station at the end of its useful life in orbit.

5.3 MODULAR GROWTH/COMMONALITY

The Space Station system shall be designed and constructed so as to grow in a modular manner. This growth includes on-orbit resources, i.e., crew, power, thermal rejection, laboratory volume, instrument mounts, services to new free flyer satellites and Orbital Transfer Vehicles, etc. The growth shall be accomplished through replication of the basic modules which provide the various functions of the Space Station such as human habitation, scientific investigation, Space Station operations, logistic resupply, servicing capability, and utility resource. The modular design shall enable a stepwise, incremental assembly of the Space Station in orbit.

The modules making up the Space Station System shall be of common construction to the extent appropriate. The modules capable of human habitation shall be of common primary structural design and have common interfaces and berthing mechanisms. The secondary structure shall be common to a TBD level. The power distribution system, information and data management system, environmental control and life support system, lighting and thermal transport shall be of common design within each subsystem with allowance for the custom installation of unique equipment required in each module.

The Utilities capability shall be designed to accommodate the maximum requirements integrated from the requirements of the Space Station base and the two Space Platforms. Attachment mechanisms shall be of a common design for payloads and modules.

For modular growth and commonality, Space Station systems with crew interfaces shall be designed in accordance with human factors standards and crew productivity goals defined in Sections 6.11 and 6.13.

5.4 TECHNOLOGY TRANSPARENCY

The indefinite life requirement imposes a derived requirement for management of the changing technology. As new technology and new mission requirements evolve, it may be beneficial to incorporate new technology into the existing system. The initial design shall accommodate such changes by, for example, establishing functional interface requirements that can be satisfied by provision of specified functions regardless of how the functions are implemented.

5.5 AUTONOMY

All elements of the Space Station system shall be capable of routine operation independent of ground support after initial startup.

Normally unmanned elements and normally manned elements which are unoccupied shall be capable of being externally controlled.

The number of non-routine contingencies and emergencies requiring ground support shall be minimized.

Operations planning and scheduling shall be performed on-board.

The degree of automation shall increase as the Space Station grows and technology becomes available.

5.6 AUTOMATION/ROBOTICS

Routine management and control of all facility management-related systems and subsystems in all elements of the Space Station system shall be carried out by on-board automated systems.

Routine resources management (including all consumables) shall be carried out by on-board automated systems.

On-board automated systems shall be designed to eliminate the need for real-time continuous monitoring by human crew or ground personnel.

Fault detection and isolation shall be an automated function for all subsystems.

Redundancy management, including reconfiguration, shall be performed automatically on-board.

Reverification of systems/subsystems elements shall be performed automatically on-board.

Collection and analysis of trend data shall be performed automatically on-board.

Operations planning and scheduling shall be performed on-board.

All automated management and control functions and data shall be accessible to crew and/or ground. Manual override control shall be available for TBD functions.

All automated systems shall provide easily accessible, complete "audit trails" for actions taken.

Automated systems shall be accessible via a "natural" or "high order" computer language that does not require special program skills on the part of the customer.

The Space Station platform shall have at least the same degree of automation on-board as the manned base.

5.7 HUMAN PRODUCTIVITY

Human productivity on the Space Station is defined as the use of man to attain utilitarian objectives within the existing resource and operational constraints. Within the Space Station, there will be an environment which optimizes the productive activities of the crew. This will be accomplished through a detailed understanding of the user requirements, the application of advanced human factors engineering practices, and the extensive use of automated systems to relieve the crew of routine tasks.

The programmatic elements associated with the goal of optimal human productivity are initially divided into Customer Services and Space Station Support. Customer Services includes those facilities and activities that are directly involved in performing services for the customer. Space Station Support involves those activities and facilities that indirectly contribute to customer services. These elements are basically akin to "habitability" and are judged to be the foundation of sustained human productivity.

A major requirement is the comprehensive and thorough application of advanced human factors engineering practices to all interfaces between man and the Space Station. This will enhance the efficiency and effectiveness of crew activities and so promote greater productivity.

5.8 MAINTAINABILITY/RESTORABILITY REQUIREMENTS

5.8.1

The Space Station maintenance and repair shall be performed on-orbit to the orbital replaceable unit (ORU) level. ORU definitions are TBD.

5.8.2

On-board checkout shall use self-test and performance monitoring capability to isolate faults to ORU's. On-board systems shall provide checkout, monitoring, warning, and fault isolation to a level consistent with crew safety/system survival and with the on-orbit maintenance and repair approach selected.

5.8.3

System design shall provide periodic or on-demand system checkout to allow early detection and maintenance of faulty equipment to avoid interruptions in service. System design shall also provide automatic fault detection and isolation.

5.8.4

Subsystem equipment shall be removable or replaceable by using installation/handling devices and standardized on-board tool kits/maintenance aids as defined by TBD. The interconnecting plumbing and wire/cable runs shall have suitable attachment, length, and mounting characteristics to facilitate removal/replacement/maintenance.

5.8.5

Out-board systems shall conform to EVA design standards (JSC-10615) for ORU replacement/maintenance.

5.8.6

Subsystem equipment shall conform to the maintainability design criteria and standards document TBD.

5.8.7

Removal/maintenance of ORU's for maintenance action shall not introduce hazardous conditions.

5.8.8

On-board spares will be carried for flight critical functions.

5.8.9

Payloads requiring service or maintenance must conform to NASA maintainability requirements TBD.

5.9 RELIABILITY

5.9.1 Redundancy/Failure Tolerance

Space Station critical components, subsystems, and/or systems shall be designed to be fail-operational/fail-safe/restorable as a minimum (except primary structure and pressure vessels (i.e., rupture mode) during all operational phases except assembly and maintenance. During assembly and maintenance, Space Station critical components, subsystems, and/or systems shall be fail-safe as a minimum. Primary structure shall have adequate safety factors to minimize the possibility of failure. Pressure vessels shall also use adequate design safety factors and be designed so that the failure mode is leakage rather than rupture. Mission critical components, subsystems, systems, and/or critical ground support hardware shall be designed fail-safe; other hardware shall be designed to be restorable.

5.9.2 Shelf Life

Space Station components shall be designed to have a minimum shelf life of TBD year(s).

5.9.3 Redundant Functional Paths

Redundant functional paths of subsystems/systems shall be designed to permit verification of their operational status in flight without removal of ORU's. Subsystem design shall provide redundancy management and redundancy status to the crew. Notification of loss of operational redundancy shall be provided immediately to the crew. Redundancies within an ORU shall be designed so that their operational status can be verified prior to installation in the Space Station subsystem without disassembly.

5.9.4 Failure Propagation

System, subsystem, or component failures shall not propagate sequentially.

5.9.5 Reliability Programmatic Requirements

Reliability programmatic requirements will be as specified in NHB 5300.4 TBD.

5.10 QUALITY ASSURANCE

Quality assurance requirements for ground-based and on-orbit operations are defined in NHB 5300.4 (TBD).

A quality assurance system shall be implemented that validates the acceptability and performance characteristics of conforming articles and materials to assure the detection and correction of all departures from the design and performance specifications. Quality assurance shall determine the requirements, methods, and inspection necessary to assure articles and materials meet their acceptance standard.

5.11 SAFETY

The Space Station and its related flight and ground elements shall be designed to meet the requirements of TBD. In addition, the Space Station and its elements shall meet the requirements of NHB 1700.7 when the elements are being operated as a Shuttle payload, either attached to or in the vicinity of the Orbiter.

The Space Station shall be designed in the following order of precedence to: (1) Eliminate hazards by removal of hazard sources and operations; (2) reduce hazards by selection of least hazardous design or operations; (3) minimize hazards by safety factors, containment provisions, isolation techniques, purge provisions, redundancy, backup systems, workarounds, EVA, safety devices, caution and warning devices, and procedures; and (4) minimize hazards through a maintainability program and adherence to an adequate maintenance and repair schedule.

5.11.1 Structures

5.11.1.1 Primary Structures

Safety requirements are TBD.

5.11.1.2 Secondary Structures

Safety requirements are TBD.

5.11.1.3 Pressure Vessels

Potentially explosive containers such as high-pressure or volatile-gas storage containers shall be placed outside of and at least TBD feet from living and operating quarters. The containers shall be isolated and protected so that failure of one will not propagate to others. Specific safety storage and handling procedures shall be provided for the following materials:

a. High-pressure fluids (TBD);

b. Volatile gases (TBD); and

c. Subcritical fluids (TBD).

All cabin pressure vessels shall be designed to leak-before-rupture criteria. A cabin wall puncture due to accident or collision shall not result in rupture. The following factors of safety shall apply:

Pressurized lines and fittings

Size (inside diameter), in.	Ultimate factor of safety
1.5	4.0
1.5	2.0

Valves, regulators, and other pressurized components shall have an ultimate factor of safety of 2.5. Pressure vessels shall be protected against overpressurization or underpressurization that could be hazardous to personnel or the Space Station. All walls, bulkheads, hatches, and seals where integrity is required to maintain pressurization shall be accessible for inspection, maintenance, or repair.

5.11.2 Mechanisms

(TBD)

5.11.3 Toxic Materials

Provisions shall be made for the containment and/or disposal of toxic contaminants. Hazardous or toxic fluid storage, conduits, and interconnects between modules shall be external to the pressurized volume. Materials used in the habitable areas shall not produce toxic constituents in the lowest pressure environments to which they will be exposed. All materials selected for use onboard the Space Station shall be approved in accordance with TBD criteria.

5.11.3.1 Materials Contamination

(TBD)

5.11.3.2 Hazardous Accumulation Of Fluids

Provisions shall be made to prevent: Hazardous accumulations of gases, or liquids to levels compatible with NHB 8060.1B, "Maximum Allowable Concentrations of Toxic Gases," and hazardous accumulation of particles. Detection of hazardous gases shall be required in critical areas and closed compartments to ensure that no hazardous conditions exist.

5.11.3.3 Drains, Vents, And Exhaust Ports

Drains, vents, and exhaust ports shall prevent exhaust fluids, gases, or flames from creating hazards to personnel, vehicles, or equipment. These vents shall not provide a propulsive effect.

5.11.3.4 Propellants

Safety requirements applicable to the on-orbit servicing of propulsion/reaction control systems using cryogens, monopropellants, and/or hypergolics are TBD.

5.11.4 Fire Control

The capability shall be provided to detect and extinguish any fire in the most severe oxidizing environment prior to failure of primary structural elements. Interior walls and secondary structure shall be self-extinguishing. All continuous nonmetallic materials shall be self-extinguishing in the most severe oxidizing environment to which they will be exposed. Means shall be provided for fire-resistant storage of medical supplies, maintenance supplies, food, tissue, clothing, trash, and other non-self-extinguishing items, where they are in use. (Note: The "most severe oxidizing environment" shall be consistent with qualification of materials and equipment; e.g., 30-percent oxygen partial pressure for cabin atmosphere.)

5.11.4.1 Exposed Surface Temperatures

Exposed surfaces within the habitable modules shall not exceed a temperature of 113°F (with a design goal of 105°F) and a low temperature of no less than 40°F.

5.11.4.2 Safe Haven And Crew Rescue

The Space Station shall provide area(s) to which the crew may retreat in the event of the development of a hazardous or life threatening condition. The safe haven areas shall be accessible at all times from anywhere within the station, isolatable from the hazardous condition, and shall contain emergency equipment including fire suppression, life support, communications, medical supplies, and provisions to maintain the crew over a period of TBD days.

The Space Station shall provide the capability to transfer crew members from the safe haven(s) to the rescue vehicle in the worst case; i.e., through an unpressurized module(s).

5.11.4.3 Explosive Devices

Provisions shall be made for arming explosive devices within TBD time of expected use. Provisions shall be made to promptly disarm explosive devices when no longer needed. All pyrotechnic devices shall meet the design requirements specified in document JSC 08060.

5.11.4.4 Battery Location/Design

Batteries shall be isolated and/or provided with safety venting systems and/or explosion protection if required by the specific type of battery.

5.11.4.5 Exposed Power Leads

The crew shall not be exposed to electrical power leads carrying higher than TBD volts at any frequency below TBD kilohertz without a minimum of TBD actions. Ground-fault protection shall be provided for circuitry or power distribution buses directly accessible by the flight crew.

5.11.5 Micro-Organisms

(TBD)

5.11.6 Medical And Psychological

(TBD)

5.11.7 Radiation

The allowable nonionizing radiation limits for the crew are as follows:

- RF energy (TBD);
- Laser energy (TBD); and
- Microwave energy (TBD).

Electromagnetic Radiation: Crew exposure to the Space Station electromagnetic environment shall not exceed recommended Occupational Safety and Health Administration (OSHA) standards, as described in TBD document.

Radiation doses that affect personnel safety must be considered from all sources, including natural environment, external isotope and reactor sources (if any), electromagnetic, and solar cosmic radiation. Materials and components subject to insidious degradation in the Space Station ionizing radiation environment shall not be used where that degradation can cause or contribute to any crew hazard. Provisions shall be made to safely dispose of any spent radioactive materials such as nuclear waste from a reactor or from other nuclear resources.

5.11.8 Earth-to-Orbit Transportation (And Abort)

Space Station assemblies transported in the Orbiter payload bay shall, as a minimum, be designed to comply with the requirements of NHB 1700.7.

5.11.8.1

The ground and/or ground system shall provide for detection and/or safe disposal of hazardous fluids or gases. Detection of hazardous gases shall be required of ground systems in critical areas and closed compartments where such detection is critical to personnel and equipment safety or ground operations.

5.11.8.2

Space Station elements payloads shall be capable of recycling to a safe condition subsequent to a launch hold.

5.11.8.3

The Space Station elements and payload shall not jeopardize the capability of the Orbiter to safely perform an Orbiter intact abort.

5.11.9 EVA

5.11.9.1

Deployment and initiation of operations considered hazardous shall be checked out from a safe location before exposing crew members to potential hazards.

5.11.9.2

Safety requirements relative to an extravehicular activity (EVA) "buddy" system or for keeping EVA crewmen within visual range are TBD. Provisions shall be made to return to the Space Station crew members who are incapacitated while performing EVA to the Space Station.

5.11.10 Fluid Management

Each fluid delivery system must contain a minimum of three mechanically independent fluid control devices in series that remain closed during all ground and flight phases (except ground servicing) until reaching a safe distance from the Space Station or manned modules. A flow control device shall isolate the fluid tank(s) from the remainder of the distribution system. This isolation valve may be opened under provisions described in section TBD. A minimum of one of the three devices shall be fail-safe; i.e., the device shall return to the closed condition in the absence of an opening signal. The opening of any flow control device shall not result in adiabatic detonation or uncontrolled release of the fluid. Each fluid system shall provide the capability to dump stored fluids in accordance with section TBD when an emergency or abort situation arises.

5.11.11 System Malfunction

5.11.11.1 Critical Functions

The Space Station system shall provide the capability for performing critical functions with any single component failed or with any portion of a subsystem inactivated for maintenance. The Space Station shall perform critical functions at a reduced capability with any credible combination of two component failures or with any credible combination of a portion of a subsystem inactivated for maintenance and failure of a component in the remaining portion of the subsystem.

5.11.11.2 Subsystem Activation/Deactivation

Subsystems shall be designed to prevent inadvertent or accidental activation or deactivation of functions or equipment that would be hazardous to personnel or the Space Station.

5.11.11.3 Hazards Warning/Corrective Actions

The Space Station shall have the capability to provide warning of hazardous conditions, identify corrective action procedures, and, in time-critical operations, provide for automatic switchover to backup systems or redundant components. Configuration status and configuration shall be provided to the crew when corrective action has been taken.

5.11.11.4 Override Capability

The crew must be able to override to automatic safing or switchover capability. All overrides shall be two-step operations with positive feedback to the initiator that reports the impending results of the override command prior to the acceptance of an execute command.

5.11.11.5 Command/Control Redundancy

Distributed accommodations for complete support of the Space Station Base shall be provided such that the data work station has the capability, as a minimum, for control of critical functions, with critical functions TBD. All controls of critical functions shall be operable by pressure-suited crewmen.

5.11.11.6 Failure Tolerance

In the event of critical on-board subsystems failure, Space Station subsystems shall be designed to minimize risk of loss of modules, injury to the crew, or damage to the Orbiter and other vehicles.

5.11.11.6.1 No credible single Space Station failure, operational error, or radio frequency (RF) signal shall result in damage to Space Station or mission/payload equipment or in the use of emergency procedures equipment.

5.11.11.6.2 No credible combination of two Space Station failures, operator errors, or RF signals shall result in the potential for crew injury or permanent loss of the Space Station. Institution of emergency procedures/equipment may be necessary but no hazardous operational level will be reached.

5.11.11.7 System Failure Notification

All systems that incorporate an automated fail-operational capability shall be designed to provide crew notification and data management system cognizance of the malfunction until the anomaly has been corrected.

6.0 SUBSYSTEM REQUIREMENTS

6.1 GENERAL

The system requirements of section 5.0 are applicable to the subsystem requirements contained herein.

6.2 STRUCTURES

The primary structure of the Space Station is that structure which reacts to or transmits loads developed by the entire Space Station System, e.g., pressure shells of modules and the structural elements of the mechanism's connecting modules.

The secondary structure of the Space Station is that structure which reacts to loads created by its own mass, by attached subsystems, and by crew activity and transmits this load to the primary structure, e.g., walls, floors, and partitions within modules; and both interior and exterior equipment mounts.

Transport structure is that structure provided as primarily temporary support for secondary structures and equipment loads during pre-launch, launch, entry, and landing and may be removed and stowed, used for alternate purposes on orbit or returned to Earth until needed. Transport structure transmits loads to the primary structure within the modules or on the outside of modules. The use of transport structure permits future growth flexibility by removing the necessity for certain permanent structures.

6.2.1 Functional Requirements

6.2.1.1 Life

The primary and secondary structures of the Space Station shall have an indefinite lifetime with provision for re-inspection, maintenance, and repair.

6.2.2.2 Strength

The primary, secondary, and transport structures of the Space Station, when used in appropriate combination, shall be of adequate strength to resist without failure all imposed environmental loads including ground testing, ground transport, launch, abort landing, orbital operations, and normal landing.

6.2.1.3 Stiffness

The primary, secondary, and transport structures of the Space Station shall be of adequate stiffness to permit each structural element to perform its function.

6.2.2 Design And Performance Requirements

6.2.2.1 Safe Life

Primary structure shall be designed for a safe orbital-operation lifetime of a minimum of TBD years. Secondary structure shall be designed for a minimum orbital-operation lifetime of TBD years.

6.2.2.2 Fail-Safe

The primary, secondary, and transport structure shall be designed so that failure of a single structural member shall not degrade the strength or stiffness of the Space Station to the extent that its crew or mission is placed in jeopardy or result in a catastrophic failure of the Space Station.

6.2.2.3 Common Structural Design

The primary structure of similar structural elements of the Space Station shall be of a common design. This concept of common hardware design shall be applied to all structural elements, systems, and modules of the Space Station.

6.2.2.4 Human Factors In Secondary Structure Design

Secondary structure shall be designed to the zero-g neutral body posture of the 5th to 95th percentile male and female person. Floor to ceiling height shall be no less than 6.5 ft. Partitions, walls, and decor shall be designed to be rearranged on-orbit to accommodate Space Station growth. Interior secondary structure shall be designed to achieve the criteria for noise reduction-standards defined in section 6.11.2.2.1.b. A common system for visual reference shall be used at activity stations throughout the Space Station. Analyses of astronaut traffic flow shall be used in design of secondary structures such as floors, ceilings, walls, and partitions. Secondary structure shall be designed to preclude physical injury to crew personnel.

6.2.2.5 Maintainability

The primary and secondary structure of the Space Station shall be designed to permit and facilitate on-orbit maintenance, inspection, or repair. Maintenance procedures shall be developed to be consistent with the fracture control requirement in section 6.2.2.11.

6.2.2.6 Damage Resistance

The primary structure of the Space Station shall be designed to be resistant to damage from external sources including impact on structure by meteoroids or space debris. The structure of the Space Station shall be designed for at least a 0.95 one-year probability of no penetrations from meteoroids predicted by the model defined in Section 2.6 of the NASA Document TM x-82478 and from space debris predicted by the model defined in TBD document. The structure of the pressurized volume shall be designed to prevent pressure loss caused by impact damage resulting from the predicted meteoroid flux. The structure of the Space Station shall be designed to provide protection against loss of functional capability of selected critical components when subjected to the predicted meteoroid flux. The probability of no meteoroid penetration shall be assessed for each of the selected critical components.

The secondary structure shall be designed to resist damage from internal sources including accidental impact on structure during crew activities. The windows of the Space Station shall be of such a design that damage to the outer side of the window shall not allow crack propogation through to the inside of the window thus causing window failure.

6.2.2.7 Margin Of Safety (MS)

All structures of the Space Station shall have positive margins of safety (MS) for all load conditions. The following relation defines MS:

$$\text{Margin of Safety (MS)} = \frac{\text{Allowable Load}}{\text{Actual Load x Factor of Safety (FS)}} - 1$$

6.2.2.8 Factors Of Safety (FS)

Factors of safety are assumed multiplicative constants applied to actual or limit loads to account for uncertainties in load definition, material properties, dimensional discrepancies, etc. The structure of the Space Station shall use the appropriate factors of safety defined in the TBD document.

6.2.2.9 Natural Frequency Requirements

The primary structure of the Space Station shall provide adequate stiffness to limit the natural resonant frequencies defined for each major element of the Space Station.

6.2.2.10 Fracture Control

The Space Station structural design shall be based on fracture control procedures which includes the assessment of fracture ctiticality to prevent structural failure due to the initiation or propogation of flaws, cracks, or cracklike defects in the Space Station structure. The structure of the Space Station shall use appropriate fracture control requirements defined in the TBD document.

6.2.2.11 Standard Structural Interfaces

The structure of the Space Station shall be designed with standard interfaces between components comprising the common modules such as end caps and cylindrical sections, between primary structure and secondary structure, and between subsystem components and their attachment to structure.

The Space Station shall not have duplicate fastener designs for structural and mechanical attachments where a standard set of fasteners and tools can be incorporated.

6.2.2.12 STS Orbiter Constraints On Module Structural Design

The launch configuration of the modules of the Space Station shall be designed to fit within the constrained launch volume of the Orbiter cargo bay. The external structural design of modules shall provide additional clearance within this volume for extraction and deployment from the cargo bay into their on-orbit configuration. The modules shall be designed to attach to the Orbiter via trunnion and keel fittings which insert in latches defined in the document JSC 07700, Volume XIV, Space Station System Payload Accommodations.

The common module mass properties of weight and center of mass shall be constrained to be compatible with the launch constraints for payload weight and center of mass defined in the document JSC 07700, Volume XIV and the launch sequence for modules for Space Station buildup.

6.2.2.13 Materials

The Space Station shall incorporated materials conforming to the requirements and guidelines defined in the TBD document.

6.3 MECHANISMS

Mechanisms of the Space Station are devices consisting of two or more parts which move relative to one another to effect a different configuration of the parts. Mechanisms often involve many disciplines such as electrical, mechanical, thermal, optical and pyrotechnic. Mechanisms operated in normal or backup modes by crew members shall be designed to accommodate human factors.

6.3.1 Functional Requirements

6.3.1.1 Performance And Design Life

The mechanisms of the Space Station shall be designed to operate correctly on-orbit to perform their design function. The mechanisms shall be designed to be tested prior to their on-orbit use through either ground-based testing (1g) or orbital demonstrations (0g) or a combination of both approaches. The mechanisms shall be designed for a minimum life adequate to perform their design function; or they shall be designed for a capability of maintenance and repair to provide the minimum life adequate to perform their design functions.

6.3.1.2 Reliability

The mechanisms of the Space Station shall be designed for fail-safe operations and the redundancy requirements of Section 5.9.2 through redundant design or manual backup. Mechanisms performing for long durations shall be designed to facilitate on-orbit maintenance and repair. The required design life and duty cycle shall be specified for each mechanism. The reliable operation of a mechanism design throughout its specified life and duty cycle shall be verified by suitable test and analysis.

6.3.1.3 Commonality

Mechanisms shall be designed as common units to be used at various locations on the station where their function is performed. Mechanisms shall be designed as independent assemblies with distinct and defineable interfaces. Mechanisms shall be designed to be removed and replaced on-orbit.

6.3.1.4 Force And Torque Constraints

Mechanisms shall be designed and verified to operate within force reaction and torque limits, defined as design requirements for each mechanism, such that their operation does not adversely impact the Space Station.

6.3.2 Design And Performance Requirements

Design and performance requirements shall be specified in this section for each of the major types of mechanisms required for the Space Station.

6.3.2.1 Berthing Mechanism

6.3.2.1.1 Definitions. Berthing is defined as the joining in space of two spacecraft or spacecraft modules by maneuvering one into contact with the other at the berthing interface and then latching the berthing mechanism.

6.3.2.1.2 Berthing Function. The interface between mechanism halves shall be identical. All active functions of the berthing systems (i.e., impact attenuation, capture latching, structural latching, etc.) shall normally be performed by one side with the other side in a passive mode. One side shall be capable of performing all active functions. Impact load attenuation and alignment subsystems of berthing systems must be designed to be commensurate with the mass properties of all Station elements configured in the Space Station.

6.3.2.1.3 Mounting. The berthing mechanism shall be designed to mount on any element of the Space Station which must be berthed to any other element.

6.3.2.1.4 Size And Shape. Berthing ports and hatches shall be sized and shaped by system requirements of EVA, package dimensions, and hatch passage through opening.

6.3.2.1.5 Hatch Operations. All hatches shall be capable of operation from either side of the hatch. Capability for equalization of pressure across the hatch shall be provided. All hatches shall close in the direction of positive pressure differential. All hatches shall be provided with hinge linkages to control hatch motion. Areas into which hatches open shall be designed so that the full-open position of the hatch does not block crew passage.

6.3.2.1.6 Utility Transfer. Utilities such as electrical signals, power, and fluids shall be transferred via modular interconnections designed into the mechanism. These interconnections, except those involving toxic or corrosive substances, shall be accessible from inside the modules and shall be designed to be installed, removed, and serviced.

6.3.2.1.7 Contact Conditions. Contact conditions for berthing operations shall be assumed as follows:

Condition	Berthing Value
Axial closing velocity, fps	TBD
Lateral velocity, fps	TBD
Angular velocity, deg/sec	TBD
Lateral misalignment, ft	TBD
Angular misalignment, deg	TBD

6.3.2.1.8 Design Life. (TBD)

6.3.2.2 Attachment Mechanism For Attached Payload Missions

(TBD)

6.3.2.3 Solar Array Drive And Power Transfer Mechanism

(TBD)

6.3.2.4 Radiator Drive And Fluid Transfer Mechanism

(TBD)

6.3.2.5 Antenna Pointing Mechanism

(TBD)

6.3.2.6 Appendage Deployment Or Erection Mechanism

(TBD)

6.3.2.7 Space Station Standard Latch

(TBD)

6.3.2.8 Remote Manipulator System (RMS)

(TBD)

6.3.2.9 Propulsion Resupply Mechanism

(TBD)

6.3.2.10 Logistic Module Changeout Mechanism

(TBD)

6.3.2.11 Payload Pointing System

(TBD)

6.4 ELECTRICAL POWER

6.4.1 Electrical Power Generation And Energy Storage

The electrical power generation and energy storage (EPGS) subsystem shall supply primary electrical power to the power distribution subsystem.

6.4.1.1 Functional Requirements

Energy storage shall be provided for eclipsed (dark side) power by electrochemical, mechanical, or other means.

6.4.1.2 Design And Performance Requirements

6.4.1.2.1 If solar arrays are used, they shall be designed to provide adequate power under any partially shadowed conditions that cannot reasonably be avoided, to preclude shadow-induced damage, and to withstand TBD accelerations resulting from orbit maintenance maneuvers. The arrays shall be sufficiently independent of Space Station orientation to assure that orbital operations or experiments can be conducted, and shall have capability for TBD degrees of freedom.

6.4.1.2.2 The power system for the initial Space Station shall provide 75 kW continuous power and be capable of growth to TBD kW for the growth station. The design shall consist of modules of such design as to provide for growth and replacement. Emergency power (TBD kilowatts and kilowatt-hrs.) shall be provided for a minimum of TBD days.

6.4.1.2.3 Standard electrical interfaces shall be provided between power sources and the power distribution system.

6.4.1.2.4 The EPGS shall provide dc and/or ac power to the distribution system.

6.4.1.2.5 Controls shall be provided for main connect/disconnect functions.

6.4.1.2.6 The power system shall be designed to function within specification in the TBD space plasma environment of the Space Station.

6.4.1.2.7 Critical loads shall be provided with emergency power in the event of primary power failure. Known critical loads include life support (TBD kilowatts) and other TBD loads.

6.4.2. Electrical Power Distribution And Control

6.4.2.1 Functional Requirements

6.4.2.1.1 Power Distribution And Control (Of Power Buses). Electrical power distribution and control shall be provided from the output of the energy sources to the various modules and primary power interfaces with the modules; energizing and de-energizing these buses and electrical outlets; monitoring energy sources and total load requirements; evaluating the source/load data; and issuing alerts in the event of impending or current contingencies. Interfaces with the information and data management system shall be TBD in performing these functions.

6.4.2.1.2 Power Conditioning. Electrical power from the power generation and energy storage devices shall be converted to TBD (ac, dc, volts, hz, phase) suitable for distribution throughout the Space Station. Electrical power from the power generation devices shall be conditioned to TBD for recharging the energy storage devices.

6.4.2.1.3 Power Protection. Power protection shall be provided for the power sources against overloads or faults in the distribution or customer systems. Power protection shall be provided for the distribution subsystem against overloads. For the customer system, power protection will be provided only to the extent of limiting the total energy dissipated in a load in the event of a fault.

6.4.2.1.4 Power Source Control. Means of selecting, connecting, and disconnecting the sources of electrical energy to the vehicle main electrical buses shall be provided such that load requirements may be met and contingencies circumvented.

6.4.2.2 Design And Performance Requirements

6.4.2.2.1 The electrical power distribution and control (EPDC) subsystem shall control the utilization and conditioning of power, storage system charging, energy source management, bus control, and contingency operations with minimum crew intervention. The EPDC shall operate at optimum efficiency and reliability without outside computational services other than advisory data, and shall provide those sequencing, switching, display, redundancy management, fault isolation, control, and fault tolerance functions required for operation as an entity. Interfaces with the information and data management system shall be TBD.

6.4.2.2.2 Primary distribution shall be TBD (ac, dc, or hybrid) and at a TBD voltage level consistent with safety but greater than 100 volts consistent with minimization of distribution losses.

6.4.2.2.3 Characteristics of primary power shall be TBD (voltage, phases, configuration, etc.).

6.4.2.2.4 Grounding scheme is TBD.

6.4.2.2.5 Diverse routing of redundant wiring and location of redundant components shall be implemented. Design shall preclude a single open circuit causing loss of a primary bus. All wiring shall be short-circuit protected at the sources with replaceable or resetable devices or be current limited.

6.4.2.2.6 Electrical connections between modules shall be accomplished by TBD.

6.4.2.2.7 The EPDC requirements for the intertransfer of electrical power between the Space Station and berthed or tethered vehicles or elements (TMS, OTV and satellite servicing support) are TBD.

6.5 THERMAL CONTROL

The thermal control system (TCS) shall be an integrated system which provides the maximum utilization of available waste heat, heat sinks, and sources and shall maintain the station structure, subsystems, and components within their specified limits during all mission phases. The level of thermal integration shall be determined considering efficient buildup/growth of the station, hardware commonality, and maintenance and repair. The system shall be capable of collecting, transporting, and rejecting waste heat not only from the spacecraft but from the customer community as well. As a goal, the design shall minimize the size and complexity of the active heat transport and rejection system through the judicious application of non-power consuming thermal control techniques to control the heat gain and loss of the various modules and subsystems. The desired characteristics of the integrated TCS is efficient management of the waste energy, high reliability, lightweight, insensitivity to vehicle orientation and maximum versatility to accept changes in heat loads. The TCS shall be designed to meet the safe haven requirements.

6.5.1 Functional Requirements

The primary functions required to support the Space Station TCS are component/environment protection, heat rejection, heat transport, efficient waste heat utilization, and thermal utility bus system for the customer community. Environment protection will be provided to control the Space Station interchange with the space environment by effecting resistance to heat gain or loss with insulation, thermal coatings and other TCS components, thus maintaining the Space Station requirements within the specified thermal requirements levels for components and/or subsystems.

6.5.1.1 Component/Environmental Protection

Component/environmental protection shall be provided by the TCS with maximum application of non-power consuming thermal control techniques with emphasis on minimizing the use of electric heaters.

6.5.1.2 Heat Rejection

The Space Station shall be designed to provide environmentally insensitive heat rejection of waste thermal energy for the nominal Space Station requirements and for the thermal utility bus for the customer community.

6.5.1.3 Waste Heat Acquisition/Transport

Waste heat acquisition/ transport shall be provided by each module to collect and transport the waste heat generated and shall provide thermal support capabilities for a wide range of customers (systems, subsystems, payloads and experimenters). The thermal acquisition/transport system shall be capable of transporting all the waste heat generated on the Space Station to a heat rejection/utilization system.

6.5.1.4 Thermal Utility Bus

The integrated thermal utility bus shall be capable of collecting and transporting waste heat from a wide variety of customers to the heat rejection radiators. The thermal utility bus system shall be capable of gathering or providing heat through a multitude of customer interfaces.

6.5.2 Design and Performance Requirements

The modularity/growth concept of the Space Station requires that it accept multiple heat loads of varying magnitudes, heat flux densities, temperature levels and locations without causing adverse heat source interactions. The thermal design shall provide for a modular growth capability and on-orbit reconfiguration capability. The thermal design shall be operational for quiescent periods or full-up periods. No single failure of a TCS component shall result in crew injury or damage to the Space Station (fail-safe). No combination of two component failures shall result in the potential for loss of life or in loss of the Space Station or Shuttle Orbiter. Commonality of all TCS components shall be standarized and replicated in terms of basic features. No attitude maneuvers of the core structure shall be required to alleviate thermal gradient effects during normal operations.

6.5.2.1 Component/Environmental Protection

The TCS shall maintain structure/components within required temperature ranges through appropriate application of coatings, insulations, isolation, and other thermal control techniques. The thermal design shall provide capability for simple make and break of interfaces with equipment, for maintenance and refurbishment, and ease of installing new equipment.

6.5.2.2 Heat Rejection

The thermal design shall be capable of interfacing multiple TBD heat loads. Each module shall provide TBD kW heat rejection capability through body mounted radiators. The Space Station shall provide a capability to reject up to TBD kW through a central heat rejection system. The body mounted radiators shall not be fluid coupled to the central radiator, but shall be thermally coupled so that load sharing may occur.

6.5.2.3 Waste Heat Aquisition/Transport

The TCS shall not require precise ordering of equipment within the thermal transport circuit to maintain temperature control. The thermal design shall provide the transport of heat between the collection interfaces and the rejection interfaces. The Space Station thermal design shall provide accommodations to interface with the ECLSS, and remove TBD kW heat loads generated by metabolic and other subsystem heat sources. The transport system will provide a multiplicity of interfaces for customer accommodations (i.e., heat exchangers, cold plates, etc.). The transport system shall be capable of transporting a total of TBD KW to the central heat rejection radiator, which will include a maximum of TBD kw of customer waste heat. The thermal design shall provide methods for transferring heat across boundaries between the structural elements of the multimodule Space Station to a heat rejection system.

6.5.2.4 Thermal Utility Bus

The thermal utility bus will provide a multiplicity of interfaces for customer accommodations (i.e.-heat exchangers, cold plates, etc.). The utility bus shall be capable of transporting TBD kW to the central heat rejection radiator, which will include a maximum of TBD kW of customer waste heat with the capability to also transport an additional TBD kW of Space Station waste heat.

6.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

The critical functions of the Space Station environmental control and life support system (ECLSS) include (1) atmosphere revitalization, (2) atmospheric pressure and composition control, (3) cabin temperature and humidity control, (4) water collection, (5) personal hygiene and waste management, (6) galley support, and (7) EVA support. The ECLSS shall have the necessary flexibility and expansion capability to accommodate the phased evolutionary growth of the Space Station. Elements shall be capable of growth in concept with time-phased increasing mission demands over an extended period and the scars for evolution to future systems must be implemented in the IOC Space Station.

Atmospheric Revitalization. Atmospheric revitalization systems shall regenerate the cabin atmosphere to provide a habitable environment for the crew. Methods for collecting and removing carbon dioxide from the cabin atmosphere are required. Sources of nitrogen and oxygen are required to provide makeup gas to the atmosphere for cabin leakage and airlock losses.

Atmospheric Pressure And Composition Control. Atmospheric pressure and composition control functions provide a method of regulating the partial and total pressure of gases in the cabin atmosphere. They shall include a method for monitoring the cabin atmosphere for contaminants and micro-organisms. A means of contaminant and microbiological control shall be provided. A means of fire detection suppression shall be provided in each module.

Cabin Temperature And Humidity Control. Cabin thermal control shall control the temperature and humidity in each pressurized module. These systems must provide atmospheric circulation throughout all areas of the pressurized modules. Humidity must be controlled by removing water from the atmosphere. A method of providing heat transport through the cabin to remove waste heat must also be provided.

Water Collection. Methods are required for collecting water from metabolic by-products. A means of pretreating any waste water to prevent chemical breakdown and microbial growth are required. Post treatment systems and a monitoring system for water quality are also required to control and monitor organic content and microbial growth prior to use.

Personal Hygiene And Waste Management. The hygiene and waste management area shall provide crew personnel hygiene services and facilities (such as showers, hand wash, commode, and urinals) which are accessible for cleaning. Also required is a method of wash water recovery to provide a source of water for use in the shower and hand wash. Solid and liquid waste collection and processing capabilities are also required.

Galley Support. Galley support will provide the requisite food and drink for the crew. The galley support will also provide for meal preparation, heating, cooling and serving. The galley support shall also provide for the cleanup and trash management of the food system.

EVA Support. The ECLS system shall provide the capability to service the regenerable extravehicular mobility unit (EMU) including the processing of the crew's metabolic carbon dioxide and waste water and the refreezing of the non-expendable heat sink.

6.6.1 Functional Requirements

The ECLSS shall perform the following functions and subfunctions:

6.6.1.1 Atmospheric Revitalization and Pressure Control

- CO_2 Removal;
- O_2 and N_2 Supply;
- Total Pressure and Composition Control;
- Trace Contaminant, Microbial Monitoring and Control, and Fire Detection/Suppression;
- Cabin Air Temperature Control and Ventilation; and
- Cabin Humidity Control.

6.6.1.2 Metabolic Water, Hygiene and Waste Management

- Potable Water Storage, Treatment and Distribution;
- Condensate, Waste Water and Urine Treatment/Processing;
- Potable and Hygiene Water Quality Monitoring;
- Solid and Liquid Metabolic Waste Collection/Processing;
- Personal Hygiene Facilities;
- Trash Processing; and
- General Housekeeping.

6.6.1.3 Galley Support

- Refrigerator and Freezer;
- Food Storage and Preparation; and
- Trash Compactor.

6.6.1.4 EVA Support

- Airlock and Umbilical Support and Control;
- EMU Servicing and Repair Equipment;
- EVA Consumables Reprocessing; and
- MMU Servicing and Repair Equipment.

6.6.1.5 Safe Haven

- Life Support Equipment;
- Hygiene Supplies;
- Clothing; and
- Escape Equipment.

6.6.2 Design and Performance Requirements

The Space Station shall provide an internal environment adequate to support and maintain crew comfort, convenience, health and well being through all operational phases. The ECLSS shall be a partially distributed subsystem, supportive of the distributive Safe Haven requirements. The ECLSS shall be automated to minimize housekeeping man-hours (on-board and ground). Electrical power of TBD kW shall be required for normal operations with a capability to provide TBD kW when in safe haven mode. Critical systems components shall be capable of undergoing maintenance without the interruption of critical services and shall be fail-safe. No two failures shall prevent maintenance of any failed system. Critical functions within the ECLSS shall be fail-operational/fail-safe.

Atmospheric leakage of each module shall be less than TBD lb/day with a maximum of TBD lb/day for the total Space Station pressurized volume.

Overboard venting of gases shall be limited to those gases that will not degrade the performance of subsystem components exposed to space (e.g., solar cells and radiator surfaces). Gas venting that is permitted shall be minimized, controlled, and nonpropulsive.

6.6.2.1 Atmospheric Revitalization and Pressure Control

The respirable atmospheric composition, temperature/humidity variation levels and ventilation levels shall meet the requirements in Table 6.6.2.1.

TABLE 6.6.2.1

RESPIRABLE ATMOSPHERE/WATER REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED*	21-DAY EMERGENCY
CO_2	mmHg	3.0 max	7.6 max	12 max
Temperature	deg F	65-75	60-85	60-90
Dew Point**	deg F	40-60	35-70	35-70
Potable Water	lb/man-day	6.8-8.1	6.8 min.	6.8 min.
Hygiene Water	lb/man-day	12 min.	6 min.	3 min.
Wash Water	lb/man-day	28 min.	14 min.	0
Ventilation	ft/min	15-40	10-100	5-200
0^2 Partial pressure***	psia	2.7-3.2	2.4-3.8	2.3-3.9
Total Pressure	psia	TBD	TBD	TBD
Diluent Gas	--	Nitrogen		
Trace Contaminants		TBD	TBD	TBD
Micro-organism Count	$/ft^3$	TBD	TBD	TBD

* Degraded levels meet fail operational criteria.

** In no case shall relative humidities exceed the range of 25-75%.

*** In no case shall the 0^2 partial pressure be below TBD psia, or the 0^2 concentration exceed TBD.

The ECLSS shall interface with the TCS through TBD heat exchangers for removal of TBD kW waste heat from the pressurized modules. The IOC Space Station shall use a regenerative process for CO_2 removal. The Oxygen and Nitrogen supply for the IOC station shall be provided by either storage or on-board generation. Consideration shall be given in a growth station to utilize on-board processes to generate oxygen. Crew members will be able to modify temperature and humidity within TBD range inside the individual modules. Ventilation shall be provided in each module of TBD to TBD feet per minute.

The capability shall exist for dumping the atmosphere of a module overboard in the event of contamination or a fire in the module. Repressurization capability shall be provided to repressurize any normally pressurized, isolatable module, independent of any other modules, one time from zero to TBD psia. Exposure of the ECLS within the normally pressurized modules to a cabin pressure between zero and TBD psia shall not create hazards or cause damage to the ECLS or the Space Station.

6.6.2.2 Metabolic Water, Hygiene and Waste Management

A process of TBD capability shall be used for recovering the dirty water from hygiene (shower and handwash) for reuse. The metabolic condensate shall be collected and stored. The crew hygiene services shall not exceed a TBD level of noise in their operation. The ECLSS shall provide a potable water dispensing station in each pressurized module to selectively dispense hot water at TBD to TBD degrees F and cold water at TBD to TBD degrees F. Consideration shall be given to utilize a phase change process to recover potable water from urine.

6.6.2.3 Galley Support

The ECLSS shall provide a refrigerator with TBD cubic feet and a freezer of TBD cubic feet for food stowage. The refrigerator shall be capable of TBD to TBD degrees F and the freezer shall be capable of TBD to TBD degrees F. Both shall be controllable within their temperature ranges.

The ECLSS shall also provide TBD cubic feet for ambient stablized food stowage. The trash compactor shall be capable of compacting trash to TBD cubic feet, and this volume shall be capable of stowage in a Logistics Module for return to Earth. Trash shall be treated to prevent microbial growth.

6.6.2.4 EVA Support

The ECLSS shall provide the capability to service and make minor repairs to the EMU, and MMU in support of EVA capabilities. This shall include replenishment of TBD consumables and modifications required for adapting EMUs and MMUs to various personnel. As EVA airlock and umbilical support and control will be provided by the ECLSS. Servicing capabilities shall be based on a minimum of 24 8-hour EVA's per week.

6.6.2.5 Safe Haven

The ECLSS shall be decentralized and each module shall have a TBD day emergency capability to support the safe haven requirements.

6.7 INFORMATION AND DATA MANAGEMENT

The Space Station information and data management subsystem (DMS) shall consist of the following: a customer services element which shall provide data management services to the customers in the space and ground environment; a core services element which shall provide data management services to the core or housekeeping functions in the space and ground environment; and a Space Station DMS which shall combine the core and customer elements for both the Base and Platforms.

6.7.1 Functional Requirements

6.7.1.1

The DMS shall provide sufficient data processing capability for each subsystem.

6.7.1.2

The DMS shall provide command and status indications to/from all subsystems for overall Space Station scheduling, control, fault detection and isolation, and maintenance scheduling.

6.7.1.3

The DMS shall provide ancillary data and resource coordination to customers via a customer dedicated data bus. The DMS shall provide interfaces for commanding customer systems independent of the core data system and shall multiplex customer data streams up to an output maximum of 300 mega bits per second (mbps) for transmission to the ground through the tracking and data relay satellite system (TDRSS) and/or the tracking and data acquisition satellite system (TDASS). The DMS shall support mission planning and scheduling and provide the information to the customer through the customer data bus interface. The DMS shall support mission planning and scheduling and provide the information to the customer through a customer data bus interface.

6.7.1.4

The DMS shall support checkout capability of individual subsystems and their redundant elements.

6.7.1.5

The DMS shall provide crew training support capability for subsystems within the Space Station. This training shall take the form of simulation software for each subsystem and is displayed through the data workstation for crew use.

6.7.1.6

The DMS shall provide data workstations and other electronic capabilities to support launch and checkout of the TMS and OTV, and support the operation of the RMS and instrument pointing system (IPS).

6.7.1.7

The DMS shall provide real-time support for data storage of TBD megabits and file management for the core services element only and TBD megabits of storage for the customer data element.

6.7.1.8

The DMS shall provide a single time and frequency reference for both the core and customer elements. The format and accuracy of this timing source is TBD.

6.7.1.9

The DMS shall provide a common data format for data transactions between all elements of the Base and Platforms. These transactions may be initiated or terminated in any element. The core and customer elements shall be independent but provisions shall be provided to enable data transmission to occur between the elements for statusing information. The format and data rates are TBD.

6.7.1.10

The DMS shall provide acquisition, encoding, scaling and formatting and displaying of physical parameters from Space Station system and subsystems to support real-time operations, trend analyses, and maintenance. Closed loop control subsystem(s) measurements are not included in this requirement.

6.7.1.11

The data communications of the DMS shall provide for the transfer of data between the subsystems through a data network that can support data rates of TBD mbps.

6.7.1.12

The data communications within the DMS elements shall provide for access to the elements for monitoring and control by the crew and the ground. To aid in maintenance, all command and data transfer between elements shall be stored for TBD days and then destroyed. The bus transactions shall be in a "packetized" format between elements of the DMS.

6.7.1.13

The DMS shall provide a data workstation as the man/machine interface. The data workstation shall be fully interactive with the DMS and interface to the data bus. All data communications shall be visible through the data workstation and allow the crew total commanding capabilities and data verification into each subsystem. The DMS shall protect the system from erroneously accepting commands that may effect crew safety and/or damage the station. The data workstation shall provide a hardcopy capability for data present on the data workstation for crew use. The data workstation shall be designed to accommodate the "zero-g" posture. The noise level of peripheral devices shall be less than TBD decibels. Each habitable module shall have provisions for a data workstation. The DMS shall allow provisions for interfacing a portable data workstation at various locations within each habitable module.

6.7.2 Design And Performance Requirements

6.7.2.1

The DMS shall be an evolvable system. The initial DMS configuration shall be expandable as the station grows to its final growth configuration to support TBD habitable modules and TBD Utility Modules.

6.7.2.2

The DMS shall be distributed and modular in both hardware and software subsystems. The capability shall exist to replace individual subsystems without impacting the total system.

6.7.2.3

The DMS shall employ standardized hardware and software modules to enable simplified maintainability and configuration management control.

6.7.2.4

The DMS shall employ a redundancy scheme as part of the fault tolerant architecture for the DMS. The DMS elements that control critical systems/ subsystems shall be fail-operational/fail-safe.

6.7.2.5

The DMS shall be maintainable through all elements. The DMS shall employ built-in test equipment that diagnoses a failure down to the ORU level. Artificial intelligence/expert systems techniques shall be used as a maintenance aid to the crew. The DMS shall be able to support operations and allow maintenance to be performed on the failed system concurrently.

6.7.2.6

The DMS shall be autonomous with respect to the ground and crew, but provisions shall be included for ground and/or crew interaction.

6.7.2.7

The DMS shall employ security techniques to preclude the reception of data by unauthorized persons.

6.7.2.8

The Space Station software shall support flight operations, onboard checkout, activation, control of subsystems, redundancy management, monitoring of Space Station functions, fault isolation, checkout and launching of OTV's and TMS's and scheduling and planning. Space Station software shall support flight and ground operations as one system. Maximum use shall be made of flight software and hardware support during ground testing of Space Station flight systems.

6.8 COMMUNICATION AND TRACKING

The communications and tracking (C&T) subsystem shall perform those functions which allow the Space Station to communicate and track other co-orbiting vehicles within its sphere of influence and communicate with the ground. In addition, the Space Station internal communications system shall provide transmission, reception, processing, control, distribution of voice, telemetry, commands, wideband data, TV, text and graphics, and tracking.

6.8.1 Functional Requirements

6.8.1.1

The C&T subsystem shall provide for the transmission, reception, processing, controlling, audio distribution, telemetry, commands, wideband data, digital data, TV, text and graphics, and tracking data.

6.8.1.2

All habitable modules, berthing ports, and airlocks shall have wireless voice communications for crew members. The C&T subsystem shall provide the capability to record, process, amplify, mix, synthesize, switch and distribute voice and/or audio to/from all internal Space Station locations and also provide voice conferencing capability between IVA, EVA, and the ground.

6.8.1.3

The C&T subsystem shall provide for the generation, processing, distribution, transmission, recording, and reception of TV and CCTV signals within the Space Station modules.

6.8.2 Design And Performance Requirements

6.8.2.1

The C&T subsystem shall provide services between the Space Station and the following vehicles whenever they are within line of sight and TBD miles.

- Co-orbiting free-flyers;
- Co-orbiting Platforms;
- Orbiter;
- OTVs;
- TMSs;
- TDRS/TDAS;
- MMUs; and
- Global Positioning Satellite (GPS).

The range, number of vehicles and services to be supplied are TBD.

6.8.2.2

The C&T subsystem shall provide acquisition and tracking of augmented and non-augmented detached vehicles for rendezvous, berthing, traffic control, and will support control during proximity and berthing operations of all vehicles, within line of sight and TBD miles.

6.8.2.3

Primary communications between the Space Station and ground shall be through TDRS/TDAS. Data rates in excess of 300 mbps shall be transmitted as individual data streams to the ground independent of TDRS or TDAS. The uplink command rate shall be 25 mbps for both core and customer data systems through TDRS.

The C&T subsystem shall provide a secondary communications link independent of TDRS/TDAS to the ground. This data link shall support an uplink data rate of TBD kbps and TBD mbps downlink. The C&T subsystem shall interface with the DMS through standard computer interfaces.

6.8.2.4

The C&T subsystem shall provide data security for all uplinks and downlinks through TDRS/TDAS. Data rates in excess of TBD mbps that are downlinked to the ground and contain experiment data that does not require data security, is exempt from encryption. The data security technique shall satisfy DOD security requirement TBD, and commercial requirements.

6.8.2.5

The primary communications bands for voice and low bit rate data (less than TBD kbps) shall be S-band or K-band. The primary band for high bit rate data (greater than or equal to TBD mbps) shall be K band but other bands shall be considered for non-TDRS communication links.

6.8.2.6

Tracking shall employ RF and/or laser techniques to support tracking TBD.

6.8.2.7

All voice data shall be digitized before transmission to the ground.

6.8.2.8

The C&T subsystem shall be a modular and evolvable system that will grow as the Space Station grows from its initial configuration of TBD modules to its growth configuration of TBD modules.

6.8.2.9

The C&T subsystem shall be maintainable at the ORU level. The C&T system shall be able to support operations and allow maintenance to be performed on the failed element.

6.8.2.10

The C&T subsystem shall provide for crew members to communicate privately with the ground. This private communications link shall include both audio and video data.

6.8.2.11

The C&T subsystem shall provide for the reception and transmission to the crew of commercial TV.

6.9 GUIDANCE, NAVIGATION, AND CONTROL (GN&C)

The GN&C subsystem, in conjunction with the Propulsion, Communication and Tracking, and the Information and Data Management subsystem, shall provide the basic functions of guidance, navigation, attitude control, orbit maintenance, proximity operations, and traffic control. The accommodations of paragraph 3.0 and the system requirements and level of redundancy specified in paragraph 5.0 shall be applicable to this subsystem. This subsystem design shall not be limited to specific devices included herein; however, these specific devices are design option considerations.

The GN&C must accommodate modular buildup of the Space Station and provide stability over a wide range of geometry and mass distribution during the assembly and configuration growth phases. The GN&C shall not be required to satisfy the performance requirements in support of payload pointing needs during the time of space construction and Station buildup.

Normal operation of the GN&C subsystem shall not require interaction or assistance from ground controllers. The Space Station GN&C subsystem shall have the capability to accept ground backup commands at all times.

6.9.1 Functional Requirements

6.9.1.1 Guidance, Navigation, And Control Subsystem Design

The provisions contained in Section 5.0 are applicable to the subsystem with the following specific requirements:

a. To accommodate commonality in the design of the GN&C among Space Station, co-orbiting platforms, and the polar platform, the design factors in consideration shall include the following:

   (1) Orientation;
   (2) Configuration;
   (3) Unmanned operations;
   (4) Propulsion; and
   (5) Servicing.

b. Provide for a safe attitude hold mode.

6.9.1.2 Guidance and Navigation (G&N)

The G&N subsystems shall:

a. Establish and maintain the Space Station state vector (position, velocity, and orientation). It shall be able to accept updates to the state vector from a second source through the communication data link.

b. Provide Space Station vector data and/or other special purpose information to support individual customer functions such as provide orientation between the navigation base and other Space Station elements.

c. Provide projections into the future of Space Station state vector to support customer functions.

d. Provide Space Station orbit maintenance, collision avoidance and reboost capability. Requirements to support Space Station deorbit are TBD.

6.9.1.3 Attitude Control And Stabilization (ACS)

The ACS subsystem shall:

a. Provide three axis attitude control torques employing both/either Momentum Exchange Devices (MED) and reaction control thrusters.

b. Provide both an automatic maneuver mode capability and a manual mode capability.

c. Provide an active momentum management system designed to control and maintain the total system momentum. This shall utilize devices such as magnetic torquers to control the momentum stored in the MED's.

d. Whenever the Shuttle Orbiter or another active vehicle is attached to the Space Station, the Station shall have a total responsibility for attitude control and the berthed vehicle ACS system shall be inhibited.

e. Provide control capability for both an inertial orientation and an earth pointing orientation. Requirements for a non-inertial sun orientation are TBD.

f. Establish and sustain a survival mode having adequate power collection in the event of multiple failures.

g. Accommodate the berthing, docking, and separation of other space vehicles with the Station (e.g., Orbiter, OTV, TMS, Station elements, and free flyers, etc.).

h. Establish and maintain the Space Station attitude information relative to one or more specified reference frames. It shall be able to accept updates for the attitude reference from an attached payload sensor.

i. Be designed to be controllable to a minimum altitude of TBD with expected worse case natural environment.

j. Requirements for providing cooperative closed loop control between the ACS and the RMS control system are TBD.

k. Control requirements for tethered operations are TBD.

6.9.1.4 Traffic Control And Proximity Operations

The guidance, navigation, and control systems shall provide the capability to support the control of traffic to and from the Space Station and to perform proximity operations to deal with traffic at the Space Station. The Space Station shall be involved with approaching and departing traffic during the time period that it is deemed necessary to protect the safety of the Space Station. The Space Station will provide relative guidance and navigation information and commands between the Space Station and Space Station traffic. The GN&C system shall have the capability to issue commands and update information for the approaching and departing vehicles. The following is a list of the required functions of the guidance, navigation, and control systems:

a. Provide relative position and velocity information between the Space Station and Space Station traffic.

b. Provide alert information and commands when Space Station traffic is in unsafe trajectories.

c. Initiate collision avoidance maneuvers.

d. Provide state vector information.

e. Specify approaching and departing trajectories to Space Station traffic.

f. Provide berthing and separation support to the Station.

g. Provide docking and undocking support between vehicles and their payloads.

h. Provide activation and deployment support of berthed/docked space vehicles.

i. Provide information management and guidance commands to co-orbiting traffic in order to maintain relative positions.

6.9.1.5 Subsystem Support Control

The GN&C subsystem shall provide pointing, computation, and search and acquisition support to other Space Station subsystems as required.

6.9.2 Design And Performance Requirements

The design and performance requirements to accomplish the functional requirements are given below.

6.9.2.1 Guidance, Navigation, And Control Subsystem Performance

The GN&C shall provide the Space Station and platform with the following capability to achieve and control orbit and orientation parameters relative to a specified reference frame.

a. Attitude accuracy and stability: Under normal operating conditions the attitude accuracy and stability of the Space Station, co-orbiting platforms, and polar platform are as follows:

	Attitude, Deg.	Stability, Deg/Sec
Space Station:	TBD	TBD
Co-orbiting Platform	TBD	TBD
Polar Platform	TBD	TBD

The attitude accuracy and stability requirements for the Space Station, co-orbiting platform, and polar platform during transient or contingency conditions (e.g., berthing/docking, separation, reconfiguration, orbit maintenance, and survival mode) are TBD.

The requirement on microgravity level for the Space Station is TBD.

b. Orbit control and accuracy: Under normal operating conditions, the GN&C in conjunction with the propulsion subsystem shall be capable of controlling the orbit of the Space Station, co-orbiting platform, and polar platform to within the following accuracy.

	Position (nmi)		
	Downrange	Radial	Out-of-Plane
Space Station	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD

	Velocity (fps)		
	Downrange	Radial	Out-of-Plane
Space Station	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD

c. Relative Position Control: Under normal operating conditions, the GN&C in conjunction with the communication and tracking and information and data subsystem shall be capable of generating commands which permit control of the relative position between either the Space Station, co-orbiting platform, or polar platform and another orbiting vehicle (utilizing either vehicle's propulsion subsystem) to within the following accuracy:

	Relative Position (nmi)		
	Downrange	Radial	Out-of-Plane
Space Station	TBD	TBD	TBD
Co-orbiting Platform	TBD	TBD	TBD
Polar Platform	TBD	TBD	TBD

6.9.2.2 Sensors

The following is a list of requirements for sensors in support of the GN&C functions:

a. Provide sensors (star trackers, sun sensors, horizon scanners, rate gyros, inertial measuring units and other sensors as needed) to define position, attitude, rates, velocity, etc., for controlling the Space Station and traffic.

b. Provide capability for on-board alignment and calibration of sensors.

c. Utilize tracking information to determine position, velocity, attitude, etc., of incoming and departing traffic at the Space Station.

d. Provide sensors to determine the status, state of health, and to diagnose malfunctions of the GN&C components.

6.9.2.3 Software And Data Processing

Requirements for software and data processing are listed below.

a. Provide processing for the momentum management function.

b. Provide software to determine the state of health of the GN&C components, to diagnose malfunctions, to isolate the malfunctioned units and to reconfigure the control systems.

c. Provide processing for alignment and calibration of sensors.

d. Provide ephemeris and other navigational data to support the Space Station navigation and navigational information supplied to the Space Station traffic.

e. Provide coordinate transformation processing germane to the Station and Station traffic.

f. Provide processing to utilize the TDRSS and the Global Position Satellites information for navigation.

g. Provide on-board models for environments, natural and induced, as well as system performance models to accomplish the functions of section 6.9.1.

h. Provide control signal processing, as needed, for momentum exchange devices, magnetic torquers, aerodynamic surfaces, reaction control systems, thrust control of reboost/deboost/collision avoidance thrusters.

i. Provide the capability to receive information from attached payloads regarding slew rates and attitude sensor data.

j. Provide support to the Instrument Pointing System.

k. Provide the capability for simultaneous operation of the different types of control effectors.

l. Provide processing to specify the trajectories of incoming and departing traffic and maneuvers of co-orbiting traffic for orbit maintenance and/or minimization of collision probability.

m. Provide processing to specify engine burn time for Station reboost, deboost, and collision avoidance together with the thruster/Station orientation.

n. Provide the capability to calculate and update Space Station mass properties.

6.9.2.4 Actuators And Effectors

Requirements for actuators and effectors are given below.

6.9.2.4.1 Momentum Exchange Devices (MED).

a. The ACS design shall employ MED's as the primary control effector.

b. The output torque level of the MED's must be sufficient to provide attitude control under steady state conditions without using the RCS. Certain transient conditions such as Shuttle docking, buildup, or rapid maneuvers shall not preclude the supplemental use of RCS.

c. The momentum capacity of the MED's must be sufficient to handle the peak cyclic momentum buildup.

d. The primary mode of desaturation of secular momentum shall be provided by gravity gradient maneuvers, moveable surfaces, magnetic torquers, or other techniques which do not require consumables.

6.9.2.4.2 Reaction Control System (RCS).

a. The propulsion system shall provide three axis torque capability. The RCS function of the GN&C system shall control this capability.

b. The propulsion subsystem shall provide the necessary thrust for all required orbit maintenance, reboost, and co-orbiting position control maneuvers. Calculations of burn times and vehicles orientation will be the responsibility of the GN&C subsystem.

c. The Station RCS system shall have the capability to be operated independently as well as concurrently and in cooperation with the MED control mode.

6.9.2.4.3 Others. Provide support for controlling other mechanisms/robotics used for proximity operations, equipment manipulation, etc.

6.10. PROPULSION

The Space Station Propulsion System (SSPS) shall receive and execute delta velocity commands from the guidance, navigation, and control subsystem. The SSPS shall provide three-axis attitude control capability and TBD-axis orbital velocity correction capability during all phases of incremental buildup and configuration changes, including berthed operations with the Orbiter and all other Space Station elements that may be permanently or temporarily berthed with the Space Station.

6.10.1 Functional Requirements

The SSPS shall provide the following capabilities.

6.10.1.1 Attitude Control

The SSPS shall provide the three-axis control torques required to overcome both internal and external disturbances to maintain attitude stabilization in the various flight modes.

6.10.1.2 Attitude Reorientaton

The SSPS shall provide the three-axis control torques necessary to provide reorientation to any attitude.

6.10.1.3 MED Desaturation

The SSPS shall provide the three-axis control torques necessary to desaturate momentum exchange devices.

6.10.1.4 Orbit Maintenance

The SSPS shall maintain the desired orbital altitude by providing TBD-axis velocity increments to make up orbital velocity losses resulting from atmospheric drag forces.

6.10.1.5 Orbit Adjustment

The SSPS shall provide TBD-axis orbital velocity increments, if required, to change the orbital altitude of the Space Station.

6.10.1.6 Function Integration

The propulsion system functions of orbit maintenance and CMG desaturation shall be performed simultaneously with a single engine firing where significant savings in propulsion system expendables are achievable.

6.10.2 Performance And Design Requirements

6.10.2.1 SSPS Thruster Locations

The SSPS thruster locations shall be selected considering, but not limited to, the following factors:

(1) Plume impingement (on Space Station and Orbiter);

(2) Cross coupling;

(3) Adequate thruster moment arm;

(4) Variation in Space Station configuration;

(5) Propellant distribution system;

(6) C.G. location; and

(7) Cabin noise/vibration.

6.10.2.2 SSPS Thrust Level

The SSPS thrust level shall reflect, but not be limited to, an optimum compromise between steady state performance, pulse performance, thrust chamber state of the art, required control authority, redundancy, reliability, allowable acceleration levels, and effect of failed-on engine.

6.10.2.3 Disturbances

The SSPS shall be capable of performing its functional requirements while being exposed to the disturbances listed below. Where practical, disturbances such as gravity gradient or venting should be utilized to enhance the stability or motion of the Space Station.

6.10.2.3.1 Internal Disturbances

(1) Crew motion;

(2) Transfer of fluids;

(3) Transfer of equipment; and

(4) Rotating machinery.

6.10.2.3.2 External Disturbances

(1) Berthing/construction;

(2) Aerodynamic forces;

(3) Gravity gradient;

(4) Solar pressure;

(5) Solar thermal effects;

(6) Earth's magnetic field;

(7) EVA and Ops activities; and

(8) Unmanned payload reorientations.

6.10.2.3.3 Venting Disturbances

(1) Leakage; and

(2) Discharge of unwanted fluids.

6.10.2.4 Propellant Reserve Margin

The SSPS shall maintain a TBD propellant reserve margin beyond the scheduled resupply time, under worst-case 3 sigma atmospheric density conditions at all Space Station altitudes and during all stages of buildup and operation.

6.10.2.5 In-Flight Component Replacement

The SSPS shall provide for in-flight replacement of critical components. This shall be satisfied by an ORU concept and/or a modular concept whereby packages containing multiple components are replaced.

6.10.2.6 System Redundancy

The SSPS shall provide a minimum of single-failure tolerance to any component after the most critical section of the SSPS has been shut down for on-orbit repair.

6.10.2.7 Non-Operating Mode

The SSPS shall be capable of being maintained in a dormant or nonoperating mode.

6.10.2.8 Thermal Control

The SSPS shall be provided with a controlled thermal environment, whether in an operating or a nonoperating mode, such that no degradation to the system occurs and no safety hazards are produced.

6.10.2.9 Contamination Control

The SSPS shall be designed to preclude contamination of the Space Station, Orbiter, TMS, OTV, satellite, externally mounted payloads, or other Space Station elements attached to, or in close proximity to, the Space Station.

6.10.2.10 Space Platform

As a design goal, the SSPS shall be capable of being utilized to provide attitude and orbit control for the space Station derived Space Platforms.

6.10.2.11 Data Management Subsystem

The SSPS shall be designed to interface with the Space Station Base data management subsystem (DMS) for system checkout, data storage, fault analysis, etc.

6.10.2.12 Inhibit

The SSPS shall provide for general system inhibit during critical Space Station operations or at other times as determined.

6.11 CREW SYSTEMS AND CREW SUPPORT

6.11.1 Functional Requirements

Dedicated areas and specialized facilities shall support crew activities and life on the station with the goal of enhancing crew productivity.

6.11.2 Design And Performance Requirements

6.11.2.1 General

Areas involving crew systems and crew support shall be designed according to standards of interior design and decoration to a degree that will facilitate human productivity. Qualified colors, textures, and non-hazardous paints will be provided for use in the physical environment consistent with the functions intended for different areas. Colors and textures will also be used to provide visual orientation cues (local vertical), equipment stowage location cues, use location aids, aesthetic variety, and contrast for the crews. There will be provision for the rearrangement of decor and change of color. Design of accommodations and facilities shall be geared to the zero-g neutral body posture, traffic patterns, congestion, cleaning, and ease of maintenance. Layout of facilities shall be supported by an analysis of traffic flow. Functional group interrelationships shall be a prime consideration in the basic arrangement.

6.11.2.2 Crew Support Compartments And Areas

6.11.2.2.1 General

a. Lighting: The lighting system shall provide interior and external illumination of intensity and types to a degree that will facilitate human productivity. Lighting shall be compatible with the "zero-g" environment and meet shadowing, contrast, glare, design criteria per NASA-STD TBD. Likewise, light shall be prevented from shining directly into the eyes of a crew member during the performance of tasks as well as during general movement about the station. Supplemental portable lighting shall be provided.

"Two-way" light switches and variable, intensity controls will be placed in convenient locations throughout the Space Station.

Night light route locators and switch illumination will be placed in areas that are frequently darkened.

b. Vibroacoustics:

Acoustics: The noise exposure within the Space Station shall be specified in terms of the equivalent A-weighted sound level.

Exposure Limits: Acceptable levels of noise exposure for a Space Station are dependent upon the type of activity conducted within the area of interest. Levels not to exceed limits for the areas listed below are as follows:

- All areas for hearing conservation: $L_{eg(24)}$ = TBD dB,
- Areas involving speech communication: $L_{eg(24)}$ = TBD dB,
- Areas involving sleep: $L_{eg(24)}$ = TBD dB, $L_{A(peak)}$ = TBD dB.

Vibration: Provision of an acceptable vibration environment must be considered from several standpoints:

(a) Use of occupied space:

- Rest/sleeping; and
- Work.

(b) Type of vibration:

- Impulsive/intermittent;
- Random; and
- Discrete frequency.

(c) Direction of vibration.

Exposure Limits: The limits are given in the form of root-mean-square (rms) acceleration levels at various frequencies of vibration for each orthogonal linear axis. Limit levels are given for various uses of the occupied space; these are critical working areas, residential (minimum complaint) areas, office, and workshop. The actual levels corresponding to each space are given in ISO/TC 108/SC 4N, "Guide to Human Exposure to Whole-Body Vibration." Significant exceeding of these levels may necessitate application of appropriate vibration isolation measures. Additionally, the International Organization for Standardization (ISO) has recommended standards for human exposure to shock and vibration in buildings. These standards are given in an addendum to ISO document ISO 2631-1974. These standards are for sinusiodal vibration. With regard to application of these standards to the Space Station environment, they should be considered as preliminary and subject to modification as additional data become available.

c. Volume: Crew private quarters should provide TBD volume. Floor to ceiling height shall be compatible with the zero-g neutral body posture of 95th percentile male crew member.

6.11.2.2.2 Crew Quarters. Private crew quarters shall be provided which will allow each crew member to be isolated from other crewmembers. Each quarter shall have background noise levels of no greater than TBD using the A-weighted scale. Lighting and ventilation shall be provided in each quarter and shall be adjustable from a sleep restraint to crew preference within a range of TBD.

Audio/video entertainment, bulletin board, reading/writing provisions shall be provided in each quarter. Personal hygiene equipment to support shaving, face and hand washing and oral hygiene shall be in each quarter. Each quarter shall contain a unisex urinal.

Quarters will be large enough to don and doff clothing easily and to rapidly egress from a sleep restraint in an emergency.

Sleep quarters will be designed to permit rearrangement of the walls, size, and reconfiguration of the quarters as development phases or crew changes require.

As a design goal, a window should be available in each crew compartments.

6.11.2.2.3 Wardroom. The wardroom/dining area shall have a TBD volume which will accommodate the entire crew simultaneously and shall also serve as a lounge, viewing and recreation area. A designated food serving/eating area shall be sized to accommodate the total number of crew members. Simultaneous dining is a goal. This area will be provided with audio/video entertainment equipment, game kits, and IVA communications. There will be trash collection devices.

Noise levels will not exceed TBD (A-weighted scale) such as to permit normal conversation. This area should be separated from work and noise generating areas.

The wardroom shall have two large observation windows that can be used for general crew viewing, and suitable crew optical viewing aids shall be provided.

6.11.2.2.4 Galley. The galley shall provide the equipment and supplies needed for the preparation and heating of food and drink, cleanup, and storage for TBD days.

Food storage shall include provisions for frozen, perishable and ambient stabilized food with an average water content of TBD lbs. water per lb dry food during normal operations. The storage and provisioning of snacks which will be available on a 24 hour basis, shall be provided. Condiments shall also be provided.

Provisions shall be made to prepare food and drinks over a range of TBD temperatures. The galley shall include a trash compactor and methods to manage wet as well as bulk trash. A handwasher shall be in close vicinity to the galley. The area around the galley shall be designed for cleanup after food and drink spills.

6.11.2.2.5 Personal Hygiene Areas. The Space Station shall provide facilities for body waste collection/disposal, personal cleanliness, and bathing. These systems shall be safe, reliable, private, and capable of being easily and conveniently cleaned. They shall not contaminate the cabin atmosphere with waste material, bacteria, toxicants, or noxious odors. Adequate body and equipment restraints shall be placed in each area.

a. Body Waste Collection: A means of collecting vomitus, fecal matter and urine from crewmembers and disposing of that material shall be provided. The facilities shall be private, and efficient to operate, sized for the 5th-percentile female to 95th-percentile male users, and maintainable and capable of being cleaned. Commode equipment noise shall not exceed TBD dB. The volume of the commode compartment shall be large enough to permit donning, doffing, and temporary storage of clothing. A handwasher shall be included inside the commode area. Separate urinals shall be in each crew-member's quarters. The commode shall be located away from the food preparation and dining area and near private crew quarters.

b. Personal Cleanliness: Shaving facilities and wash cloth wringers shall be provided. The facilities shall be capable of being cleaned on orbit and maintainable. Towels, washclothes, and a method to clean clothes shall be provided.

c. Shower: A full body shower facility shall be provided. This facility may also be used in case of chemical burns. The shower facility shall have hot, cold and mixed water controls in the shower stall, permitting hair and scalp washing, and provide a temperature controlled (heated) private dressing area. There shall be restraints to stabilize the crew while bathing in zero-g, airflow control to provide a comfortable environment while bathing, microbial control, and a means to collect waste water and transfer it to a storage tank for processing.

d. Hygiene compartment airflow shall be continuous, in a single direction, and filtered to remove hair, nail trimmings, lint, etc. before returning to the spacecraft area.

6.11.2.2.6 Exercise Area. Exercise equipment and techniques shall be provided to enable the crews to retain the requisite physical body tone. This equipment/techniques can be used for recreation also. Provisions for directable, adjustable air flow in the area of the exercise machines shall be made. Provisions shall be made for monitoring body weight and dimensional changes, and optional simultaneous reading, television viewing, or music listening.

6.11.2.2.7 Storage Areas. Storage and retrieval considerations of all required crew support items will be a major factor in the interior arrangement of the station. The various stowage items shall be located as close to their use location as is practical. The problems of restowing items shall be considered when determining required storage volumes. Color graphics shall be utilized as an aid in crew location of stowage items. Modular storage lockers shall be incorporated into the overall interior arrangement of the station. Common latching devices shall be utilized for all storage areas.

Equipment stowage provisions and restraints shall allow for identification of the stowed item prior to removal. Drawers and cabinets shall be equipped with suitable restraints to allow access, removal and restorage of equipment. Drawer storage devices shall be equipped with internal lids to prevent small items from drifting. Storage areas shall be compartmented to aid in the control of equipment during crewmembers storage and removal of equipment. Restraints for temporary constraint of equipment shall be available near storage areas and throughout the Space Station.

6.11.2.2.8 Laundry. Cleaning/washing facilities to maintain clothing shall be TBD.

6.11.2.3 Crew Support Facilities And Supplies

6.11.2.3.1 Food. Varied and complete customary meals shall be furnished for the crews. In addition, snack items shall also be provided. The food shall consist of items that can be heated to TBD^{o}, chilled to TBD^{o}, and stored at room temperature. The meals shall be nutritionally balanced, palatable, and pleasing in appearance and smell. Food supplies will take advantage of new technologies to provide milk, wine, bread, etc., as they become available. Fresh foods will be supplied every resupply period and storage that will maintain freshness for TBD days shall be provided. Condiments will be provided for variety. Bulk storage and preparation shall be provided. Food in chillers and pantries will be easy to identify and will be secured to inhibit "floating." Dishes, eating utensils, and cleaning equipment shall be supplied for use in zero-g.

6.11.2.3.2 Housekeeping. The Space Station shall be designed for a maximum of TBD hours per day/week for cleaning. All areas of the Space Station shall be cleanable and maintainable. The equipment and supplies necessary for this cleaning shall be accessible to and usable by the crews. A TBD standard will be used for the safe use of bacteriocides on open surfaces and other potential contaminants inside the Space Station.

Refuse collection and disposal: All the trash generated by the crew in using the various systems of the Space Station shall be collected and disposed of. The collection points shall be readily accessible and located near the areas of greatest trash generation. Biologically active trash shall be treated with bacteriocides to prevent it from producing gas or odors. It shall be stored and returned to Earth via the logistics systems. Trash compactors shall be considered for reducing the storage and transport volume of inorganic waste.

6.11.2.3.3. Mobility And Restraint. The station will provide crew and equipment with sufficient restraints and locomotion aids. Major hatches and doors or other passageways within a module shall facilitate crew mobility with a minimum of difficulty, avoiding major unusual body reorientations which are annoying, or which can aggravate motion sickness. The sizing and shape of such openings should fully recognize and exploit the crew neutral body position range in weightlessness.

a. Locomotion. Handholds and pushoffs will be incorporated into the interior arrangement of the module to provide the crew the ability to push themselves to any area and to be able to halt their movement at any location. Equipment design surfaces or protrusions can be used as locomotion aids and shall be designed to accommodate impact forces imparted by crew members during the translation movement and provide padding. Design passageways and locomotion aids should consider the neutral body positions in weightlessness and the inherent freedom associated with weightlessness.

   Traffic routes for translation shall be designed to consider frequency of usage and the best combinations of uses of the volumes considered for the specific traffic route. The minimizing of travel time and effort and the provision of safe, controlled translation shall also be considered.

   Equipment located in traffic routes and work station areas shall be designed to accommodate crew movement. Items that require moving in the station shall have built-in handles, and/or structural or mechanical parts suitable for gripping.

   A clear zone shall be established contiguous with each hatch and bulkhead opening, requiring all surfaces be free of hardware protrustions, sharp corners and edges, and recesses or holes.

   Hatches interconnecting modules should be no smaller than Shuttle hatches and should not be surrounded by structures which force unusual body contortions or major reorientations to accomplish passage, other than turning the body long axis to approximately perpendicular to the plane of the hatch opening.

b. Foot And Body Restraints: A positive versatile body restraint system shall be provided for crewmember use throughout the Space Station. The system shall permit a full-range of orientations about the attachment point(s). A wide range of degree of restraint shall be provided in the system from fully relaxed to rigid. The system shall permit completely free use of both hands and upper torso for manipulative tasks and shall minimize or eliminate supplemental muscle tension or foot/leg reactions against auxilliary surfaces to hold effective working attitudes. The system shall be adjustable in body length, torso length, and body location relative to the worksite. Alternate stowage at the worksite shall be provided. The restraint system architectural interface shall be common for all modules and shall utilize architectural hardware tolerant of and accommodating to the restraint device's mating receptacle(s). Conveniently located handholds shall be in place to aid in engagement and disengagement.

The restraint system shall be capable of on-orbit cleaning.

A "Restraint Kit" will be provided to permit the crew to attach semi-permanent restraints as needed. This system should be removeable.

c. Equipment Restraints. Equipment restraints will be provided to anchor every item of use that is not permanently attached to the station. Such items as velcro patches, gray tape, bungee cords, magnetic attachments, and the like are to be considered and utilized as restraints. However, this does not preclude additional restraint concepts (e.g. airflow tables). In particular, universal handholds/handrails should be designed to facilitate simple, versatile clamping devices for temporary or long-term mounting of portable devices such as TV cameras, lights, microphones, checklists, temporary tool stowage, infrequently used equipment, parts storage for maintenance, crew tethers, and other body restraint devices. Each work station shall be suitably equipped with positive restraints for conveniently holding checklists, books, and manuals open to a particular page and maintaining adequate visibility and lighting.

6.11.2.3.4 Clothing. The station shall provide crews with adequate clothing that is capable of being donned and doffed in zero-g. Cleaning/washing facilities (including a washer/dryer) to maintain that clothing shall be TBD. Clothing worn during the scheduled and off-duty activities for the crew includes under and outer garments. The clothing shall provide the wearer with adequate pockets. Flammability, cleanability, and wear resistance shall be TBD. Comfortable sleepwear shall be provided for the crews. Clothing shall be able to be reconfigured to accommodate body anthropometric changes with long duration in the zero-g environment.

6.11.2.3.5 Crew Displays and Controls. Displays and controls shall incorporate good human factors engineering design practices outlined in specifications to a degree that will facilitate human productivity. Associated peripherals, particularly printers, will be designed to acoustics requirements of Section 6.11.2.2.1.b so as not to disturb sleeping crew members.

a. Anthropometric Requirements. Crew systems shall be designed using the 5th percentile female to 95th-percentile male person anthropometric strength and size measurements adjusted for 30-year growth trends from the baseline estimate year 1985, as defined in NASA Reference Publication 1024, Anthropometric Source Book, Vol. I. Designs shall also accomodate the known 5th to 95th percentile range of crew limit segment orientations in weightlessness as described in MSFC Std 512A or other appropriate documentation.

b. Man Interface Requirements. Multifunctional controls will be used for space and weight optimization wherever possible. The following shall be designed to a degree that will facilitate human productivity: character size, display brightness and contrast, auditory characteristics; control size, direction of motion, and types of controls; display format characteristics such as use of color, color coding, and graphic versus textual display; feedback to the operator from controls, including tactile, visual, and auditory feedback requirements. Portable terminals to reduce weight and space requirements and to enhance flexibility of operations will be available.

   Switches or circuit breakers shall be protected against inadvertent operation. Multiple use displays shall be permitted. Emergency operation of controls will have a shape, texture, and location that is readily identifiable in the dark.

c. Information Processing. System status will be available to the crew through an interactive data management system query language. Inventory control shall be part of this processing system.

d. Automation. Operating controls, monitoring procedures, and system controls will be automated to a degree that will facilitate human productivity.

6.11.2.4 Crew Support Organization

6.11.2.4.1 Scheduling. Work/rest/leisure schedules shall be developed to effectively utilize the crew's time and capabilities, minimize fatigue, and maintain productivity. Equipment necessary to accomplish this shall be provided.

Provisions will be required for private communications with the ground through voice and two-way video communications.

Duty activities: Flight crew time will be scheduled day-to-day or weekly on orbit by the crew, and will be allocated as a resource.

6.11.2.4.2 Checklists And Procedures. These will be stored in the DMS and accessed through general-purpose display devices wherever possible. The capability to update the DMS data base checklists with ease and safety is required. Hard copy will be available as required.

6.11.2.4.3 Emergency Provisions. Requirements for emergency supplies and operations are TBD.

6.11.3 Medical

Medical facilities and medically trained personnel shall be available on the Space Station manned core to appropriately manage those diseases and injuries that are judged likely to occur. Personnel shall routinely monitor the environment of the Space Station for the presence of any health hazard whether due to infectious organisms, chemicals, radiation, or inappropriate operating states of spacecraft systems. The facilities and skills will also be provided to treat the occupational injuries estimated to be associated with Space Station operations. Specific prevention, diagnosis, and treatment strategies will be developed for known health hazards and occupational injuries with a probability of occurence greater than TBD per crew-year. TBD provision shall be made to prevent the spread of communicable diseases contracted by crew members on board the Space Station.

6.11.4 Social Psychological

Social/psychological criteria shall be developed to assist in the creation and operation of selection and training programs, as well as in decisions about crew mix, size, rotation, role definitions, responsibilities, and relationships, organizational systems, and the coordination of ground-to-orbit communications which involve family, friends, as well as news and entertainment. Social/psychological factors shall also be developed to assist in food program development, inventory systems, clothing selection, and architectural layouts. The goal of social/psychological programs shall be to optimize conditions that foster the quality of crew productivity.

6.12 EXTRA-VEHICULAR ACTIVITY (EVA)

6.12.1 Functional Requirements

The Space Station shall provide an EVA capability. The EVA duration will be TBD hours per crewmember per 24-hour day TBD. There will be a TBD period for each of the pre- and post-EVA operations (suit/donning/doffing and airlock egress/ingress). Prebreathe by an EVA crewmember shall not be required prior to an EVA. The space station design shall provide for simultaneous EVA's of TBD crewmembers during initial operations and for a minimum of TBD crewmembers during subsequent growth phases. EVA will be conducted using the "Buddy System."

6.12.2 Performance And Design Requirements

6.12.2.1 EMU

The extravehicular mobility unit (EMU) is an independent, anthropomorphic system that provides environmental protection, mobility, life support, and communications for the Space Station crewmember to perform EVA in Earth orbit. The EMU will consist of an assembly that includes the basic pressure components, a portable life support system, a backup life support system for emergency use, a radio communication system, and the displays and controls required to operate them.

The basic EMU will be STS compatible, and will be capable of TBD hours nominal use without a leak of such magnitude as to discontinue its use at a 0.90 probability level. The probability of rapid, physiologically dangerous decompression should be held below p=.001 throughout the TBD hour period.

The EMU should provide for operator initiated automatic closure and will be capable of donning/doffing without help in TBD minutes.

The EMU will provide a comfortable urinary bladder with male and female attachments, and be designed for ease of cleaning. The EMU shall provide protection for internal components in case of inadvertent vomiting. The EMU interior should be designed to facilitate drying, subsequent cleaning, and periodic disinfecting. Provisions for drinking fluids storage and dispensing should be included.

The pressurized EMU glove shall provide high mobility, long-term wear comfort and tactility to enable crewmembers to perform EVA operations for the entire EVA for TBD EVA days in a row without hand fatigue or discomfort.

The backpack shall support TBD hours of vigorous work without venting. The oxygen and carbon dioxide scrubbing shall be sized for at least TBD hours of vigorous activity.

The EMU shall use standard-sized components that combine with interchangeable sizing elements to fit a wide range of male and female crew members. TBD EMU's will be required. Radiation and micrometeoroid protection is required.

6.12.2.2 EVA Equipment

Translation means will include handrails/handholds/slidewires and other mobility and stability aids, such as manipulators and the manned maneuvering unit (MMU). Handholds, handrails, and restraint attachment points shall be provided along all EVA routes and at each EVA hatch. Attachment provisions for portable handholds that attach/detach shall be provided at the remote work site. These aids will not interfere with on-orbit operational envelopes.

Floodlights will be provided by the Space Station to aid EVA crew visibility in areas of high EVA activity such as the airlocks, EV satellite servicing stations, etc. Portable lights will be provided which can be mounted on rails and will be equipped with swivel or gimbal mounts.

Closed circuit television (CCTV) cameras external to the Space Station will provide a means for the crew member to perform limited pre-EVA inspections of the task areas and allow the crewmembers to verify EVA task requirements, accuracy of techniques applied, and satisfactory task completion. External storage facilities with integral handrails and supports for foot restraints, or other body restraints as appropriate, will provide for storage of EVA tools and support equipment. The storage boxes will be modularized with easy attach/detach capability for transport and worksite convenience.

Various types of EVA equipment will be included in the Space Station baseline configuration to provide the full range of EVA capabilities necessary to accomplish construction/satellite servicing and Space Station repair. These equipment types include portable foot restraints, manipulator foot restraints, as well as, tethers, mini-work stations, helmet-mounted lights, helmet-mounted television, a high resolution portable video display, and other specialized EVA tools necessary to complement the pressure-suited crewmember's capabilities.

A minimum of two MMU support stations shall be provided during growth phases. The MMU's shall be protected from the hazards of space and vacuum exposure during stowage and servicing. The MMUs shall be reserviced at the MMU Support Station automatically on the commands of a crewmember inside the Space Station. Capability of verification of adequate reservice shall be included in the automatic servicing equipment.

6.12.2.3 Airlock

An airlock shall provide the means for two suited crewmembers to transfer from the Space Station to space without having to depressurize the entire crew compartment. The Space Station shall provide a variable controlled rate of depressurization and pressurization of the EVA airlocks. The nominal rates are to be TBD psi/sec. Control of depressurization and pressurization shall be possible from both inside and outside the Space Station as well as from within and outside the airlock by a single individual. Life support umbilical connectors shall be available both inside and outside the Space Station's pressurized compartment to allow umbilical EVA operations.

The Space Station shall be designed to conserve airlock consumable losses as a result of an EVA. The airlock shall be responsive to emergency EVA requirements and shall provide all EMU support during airlock depressurization and pressurization.

The airlock shall have the capability of operating as a hyperbaric chamber.

The growth Space Station must have the capability to support TBD EVAs per day. Details regarding visual contact with an EVA astronaut are TBD. The capability shall be provided for voice communication with deployed EVA crewmembers out to TBD feet from the Space Station. The EMU caution and warning system will monitor system configuration and environmental parameters, and will provide the status of consumables, making the EMU independent of ground monitoring and control. Video communications shall be provided. There shall be the capability for discretionary downlinking of stored EVA data along a Space Station channel. Up to TBD crewmembers may be in simultaneous communication with Space Station personnel during the initial phase and up to TBD at the end of the growth phase.

6.12.2.4 Preparation and Servicing

Provisions for EVA preparation, EVA equipment stowage, recharge, checkout, maintenance (including drying), and post-EVA activities shall be made in an adjacent pressurized compartment. The maintenance area must accommodate stowage of EMU and MMU spare parts and tools. Provisions to verify the acceptability of an EMU and an MMU for EVA, following its repair or resizing, must be provided in the work area of the Space Station. The MMU shall be serviceable/repairable by an EVA suited crewmember at an external work station, and the MMU shall be capable of being disassembled in order to bring it into the Space Station.

The Space Station shall provide the capability to automatically service and check the manned maneuvering unit (MMU) and the extravehicular mobility unit (EMU) after each EVA. This includes a suit cleaning and donning station at a service/WWC facility and the processing of the crew's metabolic carbon dioxide and waste water and the refreezing of the nonexpendable heat sink. The automatic servicing facility must also perform suit drying and determine leak rates on individual suits prior to use. The entire servicing must be accomplished in TBD hours without human intervention. Servicing capabilities shall be based on TBD 8-hour EVA's per week. Repairs should be completed on orbit and TBD % and TBD hours. Management of consumables for the EVA equipment shall be provided by the Space Station service area. No donning in the airlock shall be required.

6.13 INTRAVEHICULAR ACTIVITY (IVA)

6.13.1 Work Stations

Work stations shall be provided in any location in the Space Station where a dedicated task or activity is performed exclusive of recreation, personal hygiene, food preparation, dining, housekeeping, and other off-duty activities.

6.13.1.1 Requirements And Safety Analysis

An analysis of the requirements shall be done for each work station to determine the tasks, operator activities, level of automation, tools, equipment, and safety aspects necessary to meet the requirements.

6.13.1.2 Standardization

Work stations and associated equipment shall be standardized throughout the Space Station.

6.13.1.3 Space Station Resources

Each work station shall be provided power, ventilation, heating, cooling, water, communication, and data system access.

6.13.1.4 Illumination

The illumination system shall provide adjustable task lighting, should be variable in intensity, and located so that the operator's shadow does not fall across the work area. The illumination of one work station shall not interfere with adjacent work stations.

6.13.1.5 Acoustic Isolation

Appropriate acoustic isolation will be provided within the work station to reduce the average noise level emanating from the work station to less than an average of TBD dB. Fans and any other noise sources shall be attenuated at the point of origin by engineering control measures such as isolation, absorption, and resonant cavity baffles if necessary.

6.13.1.6 Restraints

Restraint systems will be designed for work stations for zero-g body postures. The restraint system shall be adjustable to accommodate the 5th percentile to the 95th percentile male. The restraint system should be comfortable enough to allow four hours of uninterrupted use.

6.13.1.7 Storage

Materials required for the routine use of a work station will be stored in the spaces within the work station or within three feet of either side of the work station. Contents of storage areas will be clearly labeled and color coded for easy recognition.

6.13.1.8 Small Particle Capture

There will be specific provision for holding all tools, lights, clip boards, manuals, etc., that are normally employed in the use of the work station. There shall be provisions for temporarily restraining select numbers of very small equipment components, e.g., small nuts, bolts, washers, electronic components, etc.

6.13.1.9 Utility Power

All work stations will provide utility power for expanded operational use and for maintenance. The type of power and current capacity are TBD.

6.13.1.10 Window Work Stations

All work stations associated with windows for operations and scientific research will have the following items as indicated by the requirements analysis:

- Mounted voice tape recorder;
- Event timer;
- Means to mount cameras;
- Means to secure hand-held cameras;
- Small light;
- Method to secure paper and checklists;
- Writing station;
- Body restraints;
- CRT monitor and keyboard;
- Maps;
- Moving map display with an optical device to view the flight path;
- Orbital maps to identify future flight paths;
- Method of measuring angles and the horizon if appropriate;
- Control of adjacent lighting; and
- Easily deployed hood or curtain to block interior light.

Select windows shall be of a standard TBD size. Optical quality of windows is TBD pending detailed analysis of current mission requirements. Two generic classes of window work stations should be considered: One is for direct, close-in observation, visual distance estimation and control of near-station activities such as manipulator arms activity, EVA, and active docking of vehicles by the station. Wide-angle, high resolution observation is mandated for such functions by safety considerations. Closed circuit TV can be used for supplemental distance and alternate viewpoints, and for permanent records of key activities. Second is the long range observations of Earth, the cosmos, remote traffic control, and remote servicing. Such windows have requirements to enhance long-term visual surveillance, camera recording, and possible scientific instrument usage.

6.14 HEALTH MAINTENANCE

6.14.1 Functional Requirements

The health maintenance functions and capabilities shall be evolutionary on the core station. In the IOC phase, health maintenance exercise and biological monitoring equipment shall be located in the Living Quarters Module. This equipment shall be designed to be portable and relocatable to a segment of the Human Life Sciences Laboratory later in the station evolution (19TBD), at which time it shall be designated as the Health Maintenance Facility (HMF).

6.14.2 Design And Performance Requirements

6.14.2.1 Exercise Equipment

In the IOC phase, there shall be apparata for health maintenance exercise which shall be auditorally and visually interactive with the exercising crew person. Each apparatus shall be portable and stowable in this phase to allow dual use of the limited IOC Living Quarters Module volume and to allow permanent relocation to the HMF as the station evolves. The mounting fixation points shall be designed to generate no more that TBD dB SPL (A-weighted network) at a distance of 4 feet. After creation of the HMF, there shall be a total of TBD simultaneoulsy usable apparatus.

6.14.2.2 Health Maintenance Support Equipment

Exercise equipment shall be provided consistent with the knowledge of human physiologic needs in weightlessness. The equipment shall be modularized, evolutionary and designed to allow for "scar" and relocation to the HMF during Station evolution.

6.14.2.3 Operational Medical Equipment

Emergency first aid kits shall be provided in any area designated as a isolatable safe haven. These kits shall provide for stablization of an injured or ill crew person until rescue. Limited emergency surgery capability shall be provided in the Living Quarters Module at IOC, expanded to include TBD equipment and capability in the HMF after station evolution.

6.15 FLUID MANAGEMENT

6.15.1 Functional Requirements

The fluid management subsystem shall provide for long-term storage and transfer of propellants and fluids, operational monitoring, and propellant, fluid system or subsystem checkout capability in support of Space Station Subsystems and interfacing elements.

6.15.1.1 Each subsystem will provide the necessary status monitoring data of the subsystem to the data management subsystem for control and simulation.

6.15.2 Design And Performance Requirements

Specific requirements imposed on the subsystem are:

- Be designed to support the requirements of associated Space Station subsystems and interfacing elements.
- Incorporate inherent design features to allow growth, provide for thermal control and meteroid/debris protection, and minimize potential safety hazards related to storage and transfer operations.
- Be capable of acquiring and transferring propellant and fluids independent of the gravitational environment and specific orientation of any interfacing element.
- Provide for automatic or semiautomatic transfer of propellants and fluids to Space Station subsystems and interfacing elements.
- Incorporate a monitoring system in the data management subsystem with appropriate displays, controls, and caution and warning indicators that function in an automatic mode for storage and semiautomatic mode during critical opertions such as propellant transfer.

- Be capable of determining propellant and fluid quantity in the storage systems and during transfer operations for logistics resupply requirements and serivicing of interfacing elements.

- Minimize losses due to venting, boiloff, leakage, replacement, mainenance, and refurbishment. Modular ORU concepts shall be incorporated where practicable for maintenance or refurbishment.

- Provide standard propellant and fluid transfer interfaces for all interfacing elements designed to comply with safety requirements and to preclude mating to the wrong propellant or fluid connection.

- Cause no undesirable motions or moments to be imparted to the Space Station or interfacing element as the result of fluid dynamic interactions.

- Transfer operations associated with propellant or fluid resupply to the Space Station or interfacing elements shall be accomplished withing TBD hours.

- Be compatible with EVA/IVA systems and capabilities if associated crew activity is required for fluid transfer and handling operations.

- Minimize dumping/venting effects on optical sensors, by locating vents to minimize such effects.

7.0 INTERFACE REQUIREMENTS

7.1 SPACE TRANSPORTATION SYSTEM (STS)

The interface requirements between the STS and the Space Station will be identified in Shuttle ICD 19001 and shall include those interfaces necessary to transport Space Station elements to the launch site, install and service Space Station elements into the Orbiter, transport Space Station elements to orbit, activate the Space Station elements in orbit, if required, resupply the Space Station, return certain Space Station elements to Earth, and provide the necessary vehicle to vehicle environmental conditions.

7.1.1

All Space Station elements shall be capable of delivery to orbit within the Space Transportation System (STS) Orbiter. Interface provisions will be made for STS Orbiter rendezvous and berthing to facilitate the assembly, resupply, and servicing of the Space Station. The STS capabilities covering this interface are defined in JSC-07700, "Space Shuttle Program Program Description and Requirements Baseline,."

7.1.2

The Orbiter and the Space Station shall contain compatible berthing and other interface provisions to allow intertransfer of propellants and fluids, crew consumables, spares, flight data, and fluid tankage for the purpose of servicing or resupply. The specific services to be provided to the Orbiter by the Space Station during the berthed configuration are TBD.

7.1.3

The Space Station avionics, specifically including all electromagnetic emitting and receiving devices, shall be compatible with and function normally in the electromagnetic environment generated by operations with the Orbiter.

7.1.4

The Space Station shall provide for two-way communication and tracking with the Orbiter.

7.2 TELEOPERATOR MANEUVERING SYSTEM (TMS)

7.2.1 Servicing

The Space Station shall provide facilities to service the TMS, as outlined in section 6 of Appendix C. The interface shall be defined in Interface Control Document (TBD).

7.2.2 Communications And Tracking

The Space Station shall have the capability to communicate with and track the TMS. The communication links shall include line of sight and TBD through the TDRSS. The interface shall be defined in Interface Control Document (TBD).

7.2.3 Guidance, Navigation, And Control

The Space Station shall have the capability of controlling the TMS during rendezvous, berthing, and any other Space Station and co-orbiting platform proximity operations. The control system shall be designed with collision avoidance features. The interface shall be defined in Interface Control Document (TBD).

7.2.4 Proximity Data Support

The Space Station shall provide additional data support to the TMS during Space Station and co-orbiting platform proximity operations to coordinate/control TMS activities in an interactive data mode. Specific data requirements shall be defined in the Interface Control Document (TBD).

7.2.5 Electromagnetic Environment

The electrical and electronic equipment of the Space Station shall not emit radiation which interferes with the operation of the TMS. The interface shall be defined in the Interface Control Document (TBD).

7.2.6 Contamination

The TMS/Space Station interfacing systems shall be designed to preclude contamination of the Base, Orbiter, TMS, OTV, and free flyers during proximity operations. Specific contamination limits shall be defined in the Interface Control Document (TBD).

7.3 ORBITAL TRANSFER VEHICLE (OTV)

7.3.1 Servicing

The Space Station shall provide facilities to service the OTV. The requirements for the OTV servicing facilities are contained in section 7.6. The interface shall be defined in the Interface Control Document (TBD).

7.3.2 Communications And Tracking

The Space Station shall have the capability to communicate with and track the OTV. Communication links shall include line of sight, and TBD through TDRSS. The interface shall be defined in the Interface Control Document (TBD).

7.3.3 Guidance, Navigation, And Control

The Space Station shall have the capability of controlling the OTV during rendezvous, berthing, and any other close proximity operations. The control system shall be designed with collision avoidance features. The interface shall be defined in the Interface Control Document (TBD).

7.3.4 Proximity Data Support

The Space Station shall provide additional data support to the OTV during proximity operations to coordinate/control OTV activities in an interactive data mode. Specific data requirements shall be defined in the Interface Control Document (TBD).

7.3.5 Electromagnetic Environment

The OTV avionics systems, specifically including electromagnetic emitting and receiving devices shall be compatible with and function normally with the electromagnetic environment of the Space Station. The interface shall be defined in the Interface Control Document (TBD).

7.3.6 Contamination

During proximity operations the OTV/Space Station interfacing systems shall be designed to preclude contamination of the Base, Orbiter, TMS, OTV, and free flyers. Specific contamination limits shall be defined in the Interface Control Document (TBD).

7.4 PLATFORMS

7.4.1 Servicing

The co-orbiting platform shall be designed for primary servicing by the TMS with secondary servicing by EVA from the STS or the Space Station.*

7.4.2 Direct Data Transmission

A direct link to the ground for science data shall be provided for raw and/or processed data and shall be designed to work with existing typical user receiving stations. The data rate shall be TBD.

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* The polar platform shall be designed for primary servicing by the TMS with secondary servicing by EVA from the STS.

7.5 FREE FLYING SATELLITES

The satellite servicing capability of the Space Station system shall address the requirements to be defined for servicing free-flyers.

7.6 ATTACHED PAYLOADS

Attached payloads will be mounted on stationary or rotating ports provided on both the manned Space Station element and the co-orbiting platform. The resources described in section 3.3.8 will be provided to the attached instruments through these ports. The customers may attach mounts or platforms limited to TBD size and TBD volumes to these ports. The specifications for the Space Station-to-instrument interfaces will be as defined in the instrument interface control document TBD. The communications interfaces defined in section 6.8 will also be provided to the attached payloads.

7.7 SPACE STATION MODULES

The module interface requirements are TBD.

7.8 TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS)

For IOC all Space Station data formats and data transmission methodologies shall be compatible with TDRSS. The Space Station System shall be capable of transmitting/receiving data to/from the ground through TDRSS via three high speed data links and three low speed data links. The three data links shall be available for TBD minutes per orbit. Specifically, the polar platform in sun synchronous orbit at an altitude of TBD nautical miles requires a 300 Mbps downlink and 1 Mbps uplink for high speed data and Kbps downlink and 10 Kbps uplink for low speed data. The Space Station Base in 28.5 degree orbit at an altitude of TBD nautical miles requires a 260 Mbps downlink and 1 Mbps uplink for high speed data and 50 Kbits downlink and 10 Kbps uplink for low speed data. The platform in 27.5 degree orbit at an altitdue of TBD nautical miles requires a 120 Mbps downlink and 1 Mbps uplink for high speed data and 50 Kbps downlink and 10 Kbps uplink for low speed data.

7.9 GROUND SUPPORT SYSTEM

The interface requirements between the Space Station elements and the ground support equipment will consist of TBD mechanical, thermal, electrical, and software interfaces.

7.9.1 Space Station Element(s) to Checkout Facility Interfaces

(TBD)

7.9.2 Space Station System to the Mission Support Facility Interfaces

(TBD)

7.9.3 Space Station System to Customer Interfaces

(TBD)

8.0 SYSTEM VERIFICATION REQUIREMENTS

Verification of the Space Station system will be accomplished by a combination of analyses and ground and flight tests subject to the following requirements:

8.1

A verification program shall be derived and implemented to define the hardware/software tests/analyses required to demonstrate the acceptability and readiness for the intended use of all the deliverable products.

8.2

Development testing (breadboard, component, or subassembly) shall be conducted as required on all Space Station hardware and associated software where an analysis does not provide reasonable assurance that a candidate design or procedure is adequate for its intended use. Acceptance testing shall be conducted on each flight item to determine performance capability in accordance with the applicable end-item specification. Additionally, environmental acceptance testing (i.e., random vibration, thermal cycling, and thermal vacuum) shall be conducted on selected components/subsystems to screen out manufacturing defects, workmanship errors, and incipient failures not readily detectable by normal inspection techniques or through functional test.

8.3

Certification shall consist of test and/or analyses required to verify that the hardware design meets the life, environment, performance, and maintainability requirements of the end-item specifications.

8.4

Flight demonstration shall verify the performance of selected Space Station components under predetermined flight conditions, where ground test and/or analyses are inadequate or infeasible to meet test objectives.

8.5

The system verification approach shall consider the modular buildup of the Space Station to accommodate progression to the fully operational configuration.

8.6

Subsystem-to-subsystem verification shall be performed at the module level for each Space Station module.

8.7

Module-to-module interface verification shall be performed in ground facility using flight prototype interface simulation hardware. Full module-to-module verification shall consist of non-real-time dynamic flight simulations preflight and automated onboard checkout after orbital insertion and mating.

APPENDIX A

SPACE STATION PROGRAM DESCRIPTION DOCUMENT

LIST OF ACRONYMS

APPENDIX A

SPACE STATION PROGRAM DESCRIPTION DOCUMENT

List of Acronyms

ABM	Assembly and Berthing Module
ACS	Attitude Control System
BITE	Built-In-Test Equipment
C&T	Communications and Tracking
CCTV	Closed Circuit Television
CG	Center of Gravity
CMG	Control Moment Gyro
DC	Direct Current
DMS	Data Management Subsystem
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support System
EMC	Electromagnetic Compatibility
EMI	Electrical Magnetic Interference
EMU	Extravehicular Mobility Unit
EPDC	Electrical Power Distribution and Control
EPGS	Electrical Power Generation and Energy Storage
EVA	Extravehicular Activity
FS	Factor of Safety
GEO	Geosynchronous Earth Orbit
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning System
GSE	Ground Support Equipment

H_2	Hydrogen
HMF	Health Maintenance Facility
H_z	Hertz
IOC	Initial Operational Capability
IPS	Instrument Pointing System
IVA	Intravehicular Activity
KW	Killowatts
LEO	Low Earth Orbit
LRU	Line Replaceable Unit
MED	Momentum Exchange Device
MMU	Manned Maneuvering Units
MS	Margin of Safety
NMI	Nautical Mile
O_2	Oxygen
OMV	Orbital Maneuvering Vehicle (also referred to as TMS)
ORU	Orbital Replaceable Unit
OTV	Orbital Transfer Vehicle
POS	Portable Oxygen System
RCS	Reaction Control System
RF	Radio Frequency
RMS	Remote Manipulator System
SPL	Sound Pressure Level
SR&QA	Safety, Reliability, and Quality Assurance
SS	Space Station
SSPS	Space Station Propulsion System
STS	Space Transportation System

TBD	To Be Determined
TCS	Thermal Control System
TDASS	Tracking and Data Acquisition Satellite System
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TMS	Teleoperator Maneuvering System (also referred to as OMV)
TV	Television
VDC	Volts Direct Current

APPENDIX B

NATURAL ENVIRONMENT DESIGN CRITERIA

APPENDIX B

NATURAL ENVIRONMENT DESIGN CRITERIA

1.0 PURPOSE AND SCOPE

The purpose of this document is to define the natural environment design criteria for the Space Station.

2.0 GENERAL

The natural environment criteria given here shall be used in the design of the Space Station and associated equipment. Design value requirements of natural environment parameters not specifically defined below will be obtained from TM X-82473, "Terrestrial Environment (Climatic) Criteria Guidelines For Use in Aerospace Vehicle Development, "1982 Revision, and TM X-82478, "Space and Planetary Environment Criteria Guidelines For Use In Space Vehicle Development," 1982 Revision (Volume I). The Space Station sensitivity to natural environment conditions during assembly, checkout, launch, and operation shall be minimized. Required natural environmental data not contained in the above documents shall be obtained from, or approved by, the cognizant NASA contract representative prior to use.

3.0 NEUTRAL ATMOSPHERE ON-ORBIT

The Marshall Space Flight Center Model Atmosphere, Appendix A of TM X-82478, will be used to predict the nominal and variations in gas properties of the orbital altitude region of the atmosphere. The design steady-state values of the orbital neutral atmospheric gas properties shall be calculated using a value of 230 for the mean 10.7-centimeter solar flux and a geomagnetic index (ap) of 20.3 with a local time of day of 0900 hours.

Design short-time extreme values of the atmospheric gas properties shall be calculated using a value of 230 for the mean 10.7-centimeter solar flux and a geomagnetic (ap) of 400 with a local time of day of 1400 hours. These orbital neutral atmospheric gas property values represent an estimate of the conditions that may occur for a short period of time (12 hours) during an extremely large magnetic storm.

3.1 END OF LIFE REENTRY ATMOSPHERE

The NASA-MSFC Global Reference Atmosphere Model (GRAM) given in Section 3.8.1 of TM X-82473 shall be used for end of life disposal concept assessments relative to heating, breakup, and dispersion.

4.0 IONOSPHERE

The data in Section 2.8 of TM X-82478 shall be used for ionosphere environment (electron density, etc.).

5.0 RADIATION

In addition to the following, Sections 2.7 and 2.8 of TM X-82478 shall be used to develop the design radiation environment. The Space Station shall be designed to provide necessary protection to ensure that the safe dosage limits of the equipment and crew are not exceeded.

5.1 GALACTIC COSMIC RADIATION

Galactic cosmic radiation consists of low-intensity, extremely high energy charged particles. These particles, about 85-percent protons, 13-percent alphas, and the remainder heavier nuclei, bombard the solar system from all directions. They have energies from 10^8 to 10^{19} electronvolts per particle and are encountered essentially everywhere in space. The intensity of this environment in "free space" (i.e., outside the influence of the Earth's magnetic field) is relatively constant (0.2 to 0.4 particles per square centimeter per steradian per second) except during periods of enhanced solar activity when the fluxes of cosmic rays have been observed to decrease because of an increase in the strength of the interplanetary magnetic field, which acts as a shield to incoming particles. Near the Earth, cosmic rays are similarly influenced by the Earth's magnetic field, resulting in a spatial variation in their intensity. The extreme of the galactic cosmic ray environment is at sunspot minimum. The environment is 82478 for additional data on this subject.

Estimates of the daily cosmic ray dose for the various orbits are shown in table B-1. These should be considered in the Space Station design studies.

5.2 TRAPPED RADIATION

The trapped radiation environment will be taken from NASA SP-3024 or from TRECO Computer Code (National Space Science Data Center, NASA Goddard Space Flight Center) and merged with trajectory information to find particle fluxes and spectra. The fluxes and spectra will be converted to dose by data and/or computer codes provided by the NASA Johnson Space Center. See Section 2.8.2 of TM X-82478.

5.3 NEAR-EARTH ENVIRONMENT

The radiation belts trapped near the Earth are approximately azimuthally symmetric, with the exception of the South Atlantic Anomaly where the radiation belts reach their lowest altitude. The naturally occurring trapped radiation environment in the anomaly region remains fairly constant with the time although it does fluctuate with solar activity. Electrons will be encountered at low altitudes in the anomaly region as well as in the auroral zones.

5.3.1 Geosynchronous Orbit Altitude Environment

The trapped proton environment at synchronous orbit altitude is of no direct biological significance, but may cause deterioration of material surfaces over long exposure time. The proton flux at this altitude is composed of only low energy protons (less than 4 Mev) and is on the order of 10^5 protons/cm^2-sec. The trapped electron environment at synchronous altitude is characterized by variations in particle intensity of several orders of magnitude over periods as short as a few hours. However, for extended synchronous altitude missions, a local time averaged environment can be used. See Section 2.4.2 of TM X-82478 for additional data.

5.4 SOLAR PARTICLE EVENTS

Solar particle events are the emission of charged particles from disturbed regions on the Sun during solar flares. They are composed of energetic protons and alpha particles and occur sporadically and last for several days. The free-space particle event model to be used for Space Shuttle orbital studies is given in Sections 1.7 and 2.8.3 of TM X-82478.

6.0 METEOROIDS

The Space Station shall be designated for at least an 0.95 probability of no penetration from meteoroids during the maximum total time in orbit, using the meteoroid model defined in Section 2.6 of TM X-82478. Space Station meteoroid impact requirements shall be specified as follows:

a. Pressure Loss: The Space Station manned volume shall be protected from meteoroid impact damage that would result in pressure loss when subjected to the meteoroid flux model as defined in TM X-82478.

b. Functional Capability: The Space Station shall provide protection against loss of functional capability of selected critical items when subjected to the meteoroid flux model as defined in TM X-82478. The probability of no penetration shall be assessed on each item upon function criticality.

7.0 SPACE THERMAL ENVIRONMENT

The space thermal environment, including solar radiation, albedo, and Earth radiation, is shown in table B-2. Also, see Sections 1.5 and 2.5 of TM X-82478.

8.0 EARTH CONSTANTS

The values given in Sections 1.3 and 2.3 of TM X-82478 shall be used.

9.0 GROUND HANDLING AND TRANSPORTATION ENVIRONMENTS

The Space Station and components thereof shall be protected from or designed to accommodate the applicable ambient environments for the locations involved in fabrication, storage, transportation, and assembly as given in TM X-82473.

TABLE B-1

GALACTIC COSMIC RAY DOSE RATE

Orbit	Solar Maximum, rem/day	Solar Minimum, rem/day
255 nmi 55°Inclination	0.005	0.008
200 nmi - Polar	0.008	0.013
Geosynchronous	0.024	0.036

TABLE B-2

SPACE THERMAL ENVIRONMENT

Environmental Parameter:

Solar radiation, Btu/ft^2-hr.	443.7
Earth albedo, percent	30
Earth radiation, Btu/ft^2-hr	77
Pressure, [a] torr	10^{10}
Space sink temperature, °R	0

[a] Maximum value depends on insulation venting.

APPENDIX C

REFERENCE LEVEL C ELEMENT REQUIREMENTS

APPENDIX C
ELEMENT REQUIREMENTS

The Base shall be constructed on orbit from its elements, which are launched by the STS. The elements as defined in section 2.0 have individual requirements as follows. The subsystem requirements of Section 6.0 are applicable to the element requirements below.

1.0 LIVING QUARTERS MODULE

1.1 GENERAL REQUIREMENTS

The Living Quarters Module shall be launched as an integrated unit in the Orbiter payload bay. The integrated module shall provide radiation and micrometeor protection for the crew equivalent to TBD inches of TBD. The module shall contain subsystem equipment which satisfies the habitability functions for the off-duty crew.

1.2 STRUCTURES

The primary structure shall be a cylindrical pressurized shell of segmented design with end caps/closures. The elements of the primary structure shall be derived from the common module design. Features shall include but not be limited to: internal and external secondary structure attach points, TBD diameter flanges to accommodate an axial port mechanism at each end cap, capability of adding flanges to accommodate up to TBD radial port mechanisms on each cylindrical segment, and TBD. The module primary structure shall be designed for a limit (max operating) pressure of TBD psid. Proof pressure shall be 1.50 times limit pressure. Yield pressure shall be 1.65 times limit pressure and ultimate pressure shall be 2.00 times limit pressure unless required to be greater to satisfy the radiation and micrometeor protection criteria.

The secondary structure shall connect to the primary structure and support the internal and external subsystems; and provide partitions, floor and ceiling structures to separate the major functional areas within the module. The secondary structure shall separate the module into two acoustically and vibration isolated sections: the private crew quarters section; and the galley/wardroom and HMF exercise section. This separation/isolation plane shall provide acoustic and vibration isolation to meet the requirements of Section 1.1.11. There shall be a means to isolate the private crew quarters from noise, vibration and light generated elsewhere.

1.3 MECHANISMS

The module shall be equipped with a standard axial pressurized berthing mechanism on each end cone. The module shall be equipped with TBD standard TBD diameter viewports, with internally actuated external covers, located in the dining area/wardroom.

1.4 ELECTRICAL POWER

The electrical power system shall distribute and control power to the internal and external subsystems and provide the lighting within the module. The power system shall provide redundant pass-through buses of TBD levels to adjacent berthed modules. The electrical power system shall provide redundant bus power to all TBD critical subsystems located in the module.

Night light route locators and switch illumination shall be placed in TBD areas that are frequently darkened. Emergency lighting shall be provided which is activated by power failure to illuminate egress routes from the module. For further lighting details, see section 1.1.11.

1.5 THERMAL

The thermal control subsystem may be a single phase, two phase or hybrid system and shall remove the waste heat generated within the module and dissipate it to space through a body mounted radiator and/or to the central radiator by way of a single phase and/or two phase thermal bus; provide a pass-through thermal bus to adjacent berthed modules; and provide passive thermal insulation to the module interior surfaces to eliminate condensation. The body mounted radiator shall not be fluid coupled to the thermal bus(es), and shall serve as a component in the radiation/meteor protection path.

The module body mounted radiator shall be designed to make maximum use of all available external module area in order to maximize each module's heat rejection capability during each phase of Space Station evolution. The surface shall not degrade sufficiently in TBD years to cause the radiative capacity to decrease below TBD% of initial capacity at IOC. The radiator shall be designed to allow EVA refurbishment of coatings, or replacement of elements or sections by purely mechanical means.

1.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The ECLS in the module shall be supportive of TBD crew persons simultaneously with the emergency hatches-closed mode. The ECLS shall remove the CO_2 from the module atmosphere and route it TBD for further processing. The module shall be provided with a total pressure and ppO_2 regulator and valve panel which shall be supplied from commodities in the Logistics Module, and shall be capable of manual deactivation in the open hatch mode. The module shall be equipped with an atmospheric contaminant and microbial monitor unit. The ECLS shall remove moisture from the atmosphere and deliver the condensate to the water processing equipment, which also recycles the hygiene water, located in the Living Quarters Module. The ECLSS shall remove TBD BTU per hour sensible heat from the module atmosphere and ventilate all areas of the module. The ventilation supplied to each private crew quarter shall be adjustable from TBD to TBD cubic feet per minute and the direction shall be controllable. The ventilation system shall provide for TBD to TBD cubic feet per minute process air flow to each adjacent berthed module. The control parameters of section 6.5.2 shall apply to the module atmospheric revitalization and pressure control ECLS equipment.

The ECLS shall provide a potable water dispensing station in the galley to support food and drink preparation. The dispensing rate shall be metered and cumulatively measured at TBD cubic inches per minute. The dispensing system shall selectively deliver water at 40 to 45 deg F; ambient; and 110 to 120 deg F. The cold and ambient delivery volume shall be unconstrained. The hot delivery volume shall be 30.5 cubic inches with a recovery period of 5 minutes. A device shall be installed to continuously monitor the potable water quality; parameters are TBD. The potable water shall be suppled to the module from an external supply located in another module for normal operations.

The module shall provide a personal hygiene station in each crew quarter for face/hand washing, sponge/wet-wipe body hygiene, tooth brushing, and shaving. These stations shall also support the personal hygiene needs in the safe haven mode. There shall be a unisex urinal in each crew quarter. The urine from the module shall be routed to TBD for storage/return in the normal mode and may be dumped overboard in the safe haven emergency mode. Wet containment and storage of feces and vomitus and wipes shall be provided in a kit in the module for use in the safe haven emergency mode if the commode(s) is/are not located in the Living Quarters Module.

The ECLSS shall provide a TBD cubic foot refrigerator with internal temperature controlled to 35 to 40 degrees F and a TBD cubic foot freezer with internal temperature controlled to 0 to 10 degrees F. The refrigerator and freezer shall be sized to store a normal mix of food for a crew a eight for a minimum of seven days. Storage of ambient stabilized food and drink shall be provided sufficient to support TBD men for seven days plus the 21 day safe haven emergency. An oven shall be provided in the galley for hot food preparation.

The ECLSS shall provide a trash compactor in the module sized such that the compacted package dimensions shall be compatible with return to the ground in the food lockers of the Logistic Module. Provisions shall be made to add a dishwasher to the module in the evolutionary stage.

TBD inflatable rescue spheres and Portable Oxygen Supply Units (POS's) shall be stowed in the module.

A smoke and heat detection system shall be provided and TBD hand held fire extinguishers shall be distributed throughout the module.

1.7 INFORMATION AND DATA

The station Information and Data Management system shall interface with and receive cues from the ECLS control computers. The module shall contain one standard work station console connected to the station data bus. The module shall contain a pass-through data bus to support adjacent attached modules.

1.8 COMMUNICATION AND TRACKING

Each private crew quarter and each habitable compartment within the module shall contain a standard remote communications unit.

1.9 ATTITUDE AND ONBOARD FLIGHT CONTROL

NOT APPLICABLE

1.10 PROPULSION

NOT APPLICABLE

1.11 CREW SYSTEMS AND CREW SUPPORT

The module shall provide a comfortable habitable environment for an off duty crew of TBD. The private crew quarters shall be separated from the other areas of the module by an acoustic bulkhead and closure/door. Each crew quarter shall be provided with a separate entrance from a common hall/aisle/-tube. Each entrance shall be a minimum of TBD inches wide and TBD inches long. The entrances shall open outward into the common accessway. There shall be TBD private crew quarters, each with a minimum free volume of TBD cubic feet. The common wall within each pair of quarters shall be collapsible or retractable over at least TBD of its surface, at the head level, and shall be removable to accommodate configuration changes at a later date. The dimensions of each quarter shall be sufficiently large to allow a 95th percentile man to change clothing and reverse his orientation (head up to head down) comfortably and without undo effort, or exit the sleep restraint easily in an emergency. When the door is closed and the walls not retracted, the quarter shall be acoustically isolated to allow a maximum of TBD dB (TBD standard) noise to enter the quarter from activity outside the quarters area. The noise generated by equipment in the galley/wardroom/HMF shall be attenuated by engineering controls to reach no more than TBD dB (TBD standard) in these areas. TBD vibration isolation shall be provided.

Ventilation air shall be supplied to each quarter sufficiently conditioned to keep the occupied quarter between 65 to 75 degrees F and below TBD degrees F dew point. The air temperature direction and flow rate shall be adjustable by the crew from the sleep restraint. The quarters shall be equipped with a bulletin board and writing and reading capability and sufficient lighting to support these functions. An audio/video entertainment/training center shall be provided in each crew quarter. Earphones shall be used to minimize discomfort in adjacent quarters. A remote communication unit shall be in each crew quarter, which may be integrated with the audio center except that emergency warning shall not require earphones. There shall be TBD cubic feet of storage volume in each quarter for personal stowage in the local ceiling area. Each crew quarter shall be equipped with personal hygiene facilities to provide for urinating and light cleaning, shaving and tooth brushing. The colors in the crew quarters shall be TBD and the textures used shall be flat with no-gloss finishes. TBD of the area of TBD walls of each quarter shall be removable to allow color panel changeout and rearrangment. There shall be a sleep restraint in each crew quarter.

The HMF exercise equipment shall be located as far from the private quarters area as possible within the module. There shall be two exercise apparatus and each shall be auricularly and visually interactive with the crews' level of exercise. There shall be adjustable ventilation in the exercise area to provide TBD feet per minute velocity across the body of the exercising crew person. The exercise equipment and supporting functions and instruments shall be reconfigurable to another module during station evolution to separate these functions from the eating and sleeping areas.

Equipment shall be provided to store frozen, refrigerated, and ambient stabilized food in a mix to provide variety and positive stimuli for the crew. Equipment for hot food preparation shall be provided. The dining area/wardroom shall be large enough to accommodate the entire IOC crew simultaneously. There shall be audio and video entertainment and games provided for use by groups in this area.

The lighting provided in each private crew quarter shall be indirect and controllable up to TBD lumens and of TBD type at desk level and at the sleep restraint level. The lighting level for the entire interior quarter shall be a minimum of TBD lumens. The lighting intensity control shall be within reach of the crew person while in the sleep restraint, and shall be provided with a switch illuminator. The lighting in the galley, wardroom/dining area and HMF exercise area shall be indirect, of TBD type and controllable up to TBD lumens from TBD inches of the floor to TBD inches of the ceiling.

The Living Quarters Module shall provide a private or group retreat area primarily used for rest and relaxation. No station customer functions shall be supported from this module except in emergency conditions.

1.12 EXTRA-VEHICULAR ACTIVITY (EVA)

The Living Quarters Module shall be equipped with TBD inflatable rescue spheres and TBD POS's to support emergency rescue. No support for normal EVA shall be provided by the module.

1.13 INTERNAL VEHICULAR ACTIVITY (IVA) (TBD)

1.14 HEALTH MAINTENANCE

The module shall provide two exercise apparatus which are auricularly and visually interactive with the crews exercise level. There shall be instruments and equipment to monitor the bio-medical parameters and capability to support elementary life science monitoring of the crew until a more capable human life science laboratory is provided 1-3 years after IOC. The HMF equipment shall be designed to be movable to this laboratory on orbit. A first aid kit shall be provided in the module to satisfy the safe haven criteria.

1.15 FLUID MANAGEMENT

(NOT APPLICABLE)

2.0 UTILITY MODULE

2.1 GENERAL REQUIREMENTS

The Utility Module shall consist of TBD integrated unit(s) delivered in one Shuttle flight. The Utility Module shall provide TBD pressurized area for TBD equipment and TBD unpressurized area for TBD equipment. All utility module subsystems shall be designed with crew access for in-orbit maintenance or replacement by either EVA or by TMS.

The Utility Module shall accommodate the integrated maximum requirement for the base station, the polar platform and the low inclination platform for power, thermal control, data, communications, attitude control, and propulsion. Deviations from full commonality of the Utility Module/platforms are acceptable only if technical requirements or program cost benefits can be quantified.

2.2 STRUCTURES

The basic structure of the Utility Module shall support the systems described below during ground operations, launch, and on-orbit operations. Structure shall be provided to protect the equipment from the space (radiation, active oxygen, micrometeroid and TBD) environment. Protection to a level of TBD shall be provided. Access by EVA crew or by TMS for equipment maintenance and change out shall be provided.

2.3 MECHANISMS

The Utility Module shall provide TBD attach points for other station modules or platform payloads. Hard points shall be provided to attach the power generation, thermal control, communication, propulsion, attitude control, and TBD devices to the basic structure where required and provide separation, sweep angle, field of view, etc.

2.4 ELECTRICAL POWER

The Utility Module shall provide electrical power to the station bus. It shall include built in capability (scar weight) for future power system growth. It shall include a power generation subsystem; a power storage subsystem and a power conditioning and distribution subsystem.

2.5 THERMAL CONTROL

This module shall have a thermal control/radiator system to reject TBD KW heat from the entire Space Station Base. The central radiator on the utility module shall dissipate the heat collected by the thermal bus from the other modules. The thermal control system shall include built-in capability (scar weight) for future thermal control growth.

2.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

(TBD)

2.7 INFORMATION AND DATA

The Utility Module shall contain the data control center (node) as part of the Space Station's distributed information and data management system. This data control center shall support the consoles or keyboard stations located in other modules.

2.8 COMMUNICATIONS AND TRACKING

The communications equipment located in the utility module shall provide external communications capability to the STS, free flying elements, and the ground via the TDRSS and via S and K-Band transponders, receivers, and associated antennas.

2.9 ATTITUDE AND ORBIT CONTROL

The Utility Module shall provide attitude control capability for the Space Station Base. Possible devices to be used are momentum exchange devices, control moment gyros, magnetic torquers and/or an attitude control propulsion system. This system shall be capable of future growth.

2.10 PROPULSION

The Utility Module shall provide orbital reboost capability by means of a thrustor module propulsion system. This system shall be capable of future growth.

2.11 CREW SYSTEMS AND CREW SUPPORT (TBD)

2.12 EXTRA VEHICULAR ACTIVITY (EVA)

The Utility Module shall be equipped with foot holds, hand holds and TBD other restraints to allow EVA maintenance. Exterior and interior lighting shall be provided.

2.13 INTERNAL VEHICULAR ACTIVITY (IVA) (TBD)

2.14 HEALTH MAINTENANCE

NOT APPLICABLE

2.15 FLUID MANAGEMENT

NOT APPLICABLE

3.0 ASSEMBLY AND BERTHING MODULE (ABM)

3.1 GENERAL REQUIREMENTS

The ABM shall be launched as an integrated unit in the Orbiter payload bay. The ABM shall provide radiation and micrometeor protection for the crew equivalent to TBD inches of TBD. The module shall act as an assembly device to provide for connection of other modules, allowing the station to grow in three dimensions. The module shall contain the EVA airlock and associated support equipment, shall contain (TBD) command and data work station for station and experiment control, and shall contain the OTV, TMS, and RMS control equipment. The Space Station configuration will determine the number of ABM's required to assemble the Space Station. If more than one module is required, it shall be furnished with essential subsystems only.

3.2 STRUCTURES

The primary structure shall be a cylindrical segmented pressurized shell with end caps/closures. The elements shall be derived from the common module primary structure. The EVA airlock shall be internal to the module and its pressure shell shall be considered as primary structure. The EVA airlock shall be designed for a maximum limit pressure of 15 psid below and 30 psid above ABM cabin pressure.

The secondary structure shall connect to the primary structure and support the internal and external subsystems; and provide partitions, floor and ceiling structures to separate the major functional areas within the module. The secondary structure shall attenuate the noise generated by subsystems and equipment within the module to levels described in section 1.3.11.

3.3 MECHANISMS

The module shall be equipped with a standard axial pressurized berthing mechanism on each end cap and TBD standard pressurized berthing mechanisms at TBD radial port flanges. The module shall be provided with TBD standard radial experiment ports and one observation window or equivalent for RMS, TMS and OTV control and observation. The module interface with the servicing truss/RMS track mechanisms is TBD The outer and inner EVA airlock hatches are described in section 1.3.12.

3.4 ELECTRICAL POWER

The electrical power subsystem shall distribute and control the power to the internal and external subsystems and provide the lighting within the module (see section 1.3.11 for lighting details). The power system shall provide redundant pass-through buses of TBD levels to adjacent berthed modules. The electrical power system shall provide redundant bus power to all TBD critical subsystems located in the module.

3.5 THERMAL

The thermal control subsystem may be a single phase, two phase or hybrid system and shall remove the waste heat generated within the module and dissipate it to space through a body mounted radiator and/or to the central radiator by way of a single phase and/or a two phase thermal bus; provide a pass-through thermal bus to adjacent berthed modules; and provide passive thermal insulation to the module exterior and interior surfaces to eliminate condensation. The body mounted radiator, if required, shall not be fluid coupled to the thermal bus(es), and shall serve as a component in the radiation/meteor protection path. The module body mounted radiator shall be designed to make maximum use of all available external module area in order to maximize each module's heat rejection capability during each phase of Space Station evolution. The surface shall not degrade sufficiently in TBD years to cause the radiative capacity to decrease below TBD% of initial capacity at IOC. The body mounted radiator shall be designed to allow EVA refurbishment of surfaces, or replacement of elements or sections by purely mechanical means.

3.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The ECLS subsystem (ECLSS)in the module may be supportive of TBD crew persons simultaneously in the emergency hatches-closed mode depending on the safe haven philosophy. The ECLSS may remove the CO2 from the module atmosphere and route it to the TBD for further processing. The module shall be provided with a total pressure and 02 partial pressure control panel which shall be supplied from commodities in the Logistics Module, and shall be capable of manual deactivation. The module shall be equipped with an atmospheric contaminant and microbial monitor unit. The ECLSS shall remove moisture from the atmosphere and deliver the condensate to the Living Quarters Module for treatment/processing. The ECLSS shall remove TBD BTU per hour sensible heat from the module atmosphere and ventilate all areas of the module at between TBD and TBD feet per minute. The ventilation system shall provide for TBD to TBD cubic feet per minute processed air to each adjacent berthed module. The control parameters of section 6.2 shall apply to the module atmospheric revitalization and pressure control equipment.

A smoke and heat detection system shall be provided and TBD hand held fire extinguishers shall be distributed throughout the module.

3.7 INFORMATION AND DATA

TBD standard consoles shall be located in the module for station, customer experiments, and RMS/TMS/OTV control. The module shall contain pass-through station and experiment data buses to support adjacent strings of attached modules and unmanned payloads.

3.8 COMMUNICATION AND TRACKING (C&T)

The C&T system shall provide each console with access to any other remote C&T unit in the station. The central C&T station shall be located in the module, and shall couple all remote units with EVA crew persons, Orbiter and all off-core elements, and the ground stations by interfacing with the transmitting and receiving equipment on the Utility Module.

3.9 ATTITUDE AND ORBIT CONTROL

The module shall act as the command center for core station attitude and orbit control through the command and data work station consoles.

3.10 PROPULSION

NOT APPLICABLE

3.11 CREW SYSTEMS AND CREW SUPPORT

In the normal mode, the module shall act as the station control centers for operations planning, core station master control, externally mounted experiment pointing and control, and as a node for off-station element and ground data links. As such, the module shall be divided into logical work areas by secondary structure partitions and lighting controls organized around the individual standard consoles. Each console work station shall accommodate two crew persons simultaneously. Restraints shall be provided for the crew in each work stations and hand rails shall be located throughout the module interior/exterior to facilitate crew movement between work station and during EVA.

Ambient noise levels in the work areas of the module shall not exceed TBD db (TBD standard).

Color selection and texture shall be chosen to insure non-glare conditions.

The module act as an emergency safe haven, with hatches closed, for a crew of TBD. As such, the module shall contain CO2 removal, O2, N2 and potable water supply, overboard urine dump, feces/vomitus bags, hygiene wet wipes, ambient stabilized food, and first aid equipment and commodities for 21 days. TBD pressurizable rescue spheres and portable oxygen supplies shall be stowed in the module. Whether or not the module will act as a safe haven depends on station configuration and safe haven philosophy chosen.

The lighting intensity at each work station/console shall be locally adjustable by the crew while positioned at the console. The undiminished lighting intensity throughout the module shall be TBD lumens from TBD inches off the floor to TBD inches below the ceiling.

3.12 EXTRA-VEHICULAR ACTIVITY (EVA)

The module shall be equipped with an EVA airlock internal to the module cylindrical pressure shell. The EVA airlock shall provide TBD cubic minimum volume to support the occupancy of two suited crew persons and TBD cubic feet of tools/equipment/experiments simultaneously. Depress/repress controls shall be accessible from inside the ABM Module, inside the airlock and outside the Core Space Station. The airlock shall be capable of supporting two EVA crew persons simultaneously on umbilicals of TBD feet length each. The airlock shall have primary and emergency lighting.

In the normal mode the airlock shall be pressurized at a rate of TBD psi per minute and depressurized at a rate of TBD psi per minute in either the EVA or hyperbaric mode. A minimum of 90% of the airlock internal mass of O_2 and N_2 shall be collected during each depressurization for reuse during the subsequent pressurization in both the EVA or hyperbaric normal modes. Emergency pressurization of TBD psi per minute and depressurization at TBD psi per minute shall be provided directly from high pressure gas and direct dump. The airlock shall be capable of serving as a hyperbaric chamber at 45 psia while occupied by two persons. The EVA airlock shall be provided with a TBD cubic foot tool pass-through lock from the ABM to the EVA airlock interior when fully depressurized or at hyperbaric pressure. The EVA airlock shall provide hangers/brackets for storage of two EMU's during non-EVA operations. The EVA airlock shall be provided with two outward opening crew hatches: one to the ABM and one for the station exterior. The exterior port and hatch mechanism may accommodate Orbiter berthing (TBD).

The module shall accommodate the stowage attachment of two Manned Maneuvering Units on its external surface. The MMU's, in whole or in parts, shall be brought inside for maintenance.

Storage hangers/brackets for TBD EMU's shall be provided within the ABM in the EMU service area. The EMU servicing area shall allow two EMU's to be recycled to support back-to-back EVA's in TBD hours. Cleaning, servicing and maintenance equipment and commodities shall be provided in the area. The MMU's shall be repaired here also.

3.13 INTERNAL VEHICULAR ACTIVITY (IVA)

The module shall be designed to allow entrance and mobility for an EVA crew person for emergency maintenance/repair.

3.14 HEALTH MAINTENANCE

NOT APPLICABLE

3.15 FLUID MANAGEMENT

NOT APPLICABLE

4.0 OPERATIONS MODULE

4.1 GENERAL REQUIREMENTS

The Operations Module shall be launched as an integrated unit in the Orbiter payload bay. The integrated module shall provide radiation and micrometeor protection for the crew equivalent to TBD inches of TBD. The module shall be designed to be outfitted in two stages: the first stage being "Core Laboratory" made up of primary structure, basic subsystems, basic secondary structure, and TBD which shall be common to all laboratories; and the second stage being as a specialized fully integrated Life Sciences, Materials Processing R&D, or TBD Laboratory containing specialized subsystems, science ports and experiment support equipment. While it is not mandatory to maintain a uniform local vertical throughout the entire module, it shall be mandatory that each work station and area maintain a local vertical for all operationally related tasks to be performed at that station or area.

4.2 STRUCTURES

The primary structure shall be a cylindrical segmented pressurized shell with end caps/closures. The elements shall be derived from the basic design of the common module primary structure.

The secondary structure shall mount to the primary structure and be designed to be outfitted in two stages: the first stage being that secondary structure that supports the subsystems associated with the "Core Laboratory"; and the second stage being that secondary structure that supports the experiment support equipment and the experiments themselves associated with the specialized fully integrated laboratory. The secondary structure shall attenuate the noise generated by subsystems and experiment support equipment within the module to levels described in section 13.11.

4.3 MECHANISMS

The module shall be equipped with a standard axial pressurized berthing mechanism on each end cap of TBD inner diameter, TBD standard fixed unpressurized radial experiment ports and TBD standard pointing unpressurized radial experiment ports/mechanisms. The radial experiment ports/mechanisms shall be controllable from the ABM and be transparent to the internal laboratory users.

4.4 ELECTRICAL POWER

The electrical power subsystem shall distribute and control the power to the internal and external subsystems and equipment and provide the lighting within the module. The "Core Laboratory" subsystems shall be powered from subsystem buses which are common to all laboratories. The experiment support equipment and experiments shall be provided power from experiment buses. "Core Laboratory" design shall provide a choice of two levels of intramodule experiment power distribution: a total of 25 kW max or TBD kW max. The configuration chosen for final installation will depend on the total customer power of the integrated laboratory (25 kW for MPS Lab; TBD kW for Life Sciences Lab). TBD customer outlets shall be standard convenience types, easily accessible for reconfiguration whether supporting rack mounted or work bench mounted experiments or experiment support equipment. There shall be TBD VAC outlets and/or TBD VDC outlets distributed throughout the module; voltage, frequency and current limiting characteristics are TBD. TBD of the total outlets shall be capable of receiving the maximum power available.

4.5 THERMAL

The thermal control subsystem may be a single phase, two phase or hybrid system and shall remove the waste heat generated within the module and dissipate it to space through a body mounted radiator and/or to the central radiator by way of a TBD single, two phase or hybrid thermal bus(es); provide a pass-through thermal bus to adjacent berthed modules; and provide passive thermal insulation to the module exterior and interior surfaces to eliminate condensation. The body mounted radiator shall not be fluid coupled to the thermal bus(es), and shall serve as a component in the radiation/meteor protection path. The module body mounted radiator shall be designed to make maximum use of all available external module area in order to maximize each module's heat rejection capability during each phase of Space Station evolution. The surface shall not degrade sufficiently in TBD years to cause the radiative capacity to decrease below TBD% of initial capacity at IOC. The body mounted radiator shall be designed to allow EVA refurbishment of coatings, or replacement of elements or sections by purely mechanical means. The experiment thermal bus shall be designed to allow a choice of two levels of heat rejection capacity to be integrated into the laboratory: the first being high total customer load of TBD BTU per hour at TBD °F ± TBD °F (MPS Lab); and the second being low customer load of TBD BTU per hour at TBD °F ± TBD °F (Life Sciences Lab). The active thermal control fluid within the habitable volume shall be non-flammable and nontoxic.

There shall be TBD locations inside the module for experiments and experiment support equipment to connect to the thermal bus(es). Each location shall provide two temperature levels: TBD °F for low temperature experiments and TBD °F for high temperature experiments and support equipment. The thermal bus(es) shall provide the capability for total maximum heat load at TBD percent of the locations to match the electrical power dissipated.

4.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The subsystem (ECLSS) in the module shall be supportive of TBD crew persons simultaneously in the emergency hatches-closed mode. The ECLSS shall remove the CO_2 from the module atmosphere and route it to TBD for further processing. The module shall be provided with a total pressure and O_2 partial pressure control panel which shall be supplied with commodities from the Logistics Module for normal operations and from Operations Module sources in the emergency mode, and shall be capable of manual deactivation in the open hatch mode. The module shall be equipped with an atmospheric contaminant and microbial monitor unit. The ECLSS shall remove moisture from the laboratory atmosphere and deliver the condensate to TBD for treatment/processing. The ECLSS shall remove TBD BTU per hour of sensible heat from the module atmosphere and ventilate all areas of the module between TBD to TBD feet per minute. The ventilation system shall provide for TBD to TBD cubic feet per minute processed air to each adjacent berthed module. The control parameters of section 6.6 shall apply to the module atmospheric revitalization and pressure control equipment. The ECLSS shall provide an ambient water dispensing station for drinking and food reconstitution, and sufficient water storage to support TBD crew persons in the safe haven emergency mode. A direct overboard dumping unisex urine system and a capability for feces and vomitus collection shall be provided in a kit in the module to support the safe haven mode. A first aid kit shall be provided in the module. A smoke and heat detection system shall be provided and TBD hand held fire extinguishers shall be distributed throughout the module. Consideration shall be given to a central fire fighting system for the module.

4.7 INFORMATION AND DATA

TBD standard information and data management work station consoles shall be located in the module for customer experiment control. One of the consoles shall be used for station control in the emergency mode. The module shall contain passthrough station and experiment data buses to support adjacent strings of attached modules.

4.8 COMMUNICATION AND TRACKING

The module shall be equipped with TBD standard remote communications units interfacing with the central communications subsystem located in the ABM.

4.9 ATTITUDE AND ONBOARD FLIGHT CONTROL

NOT APPLICABLE

4.10 PROPULSION

NOT APPLICABLE

4.11 CREW SYSTEMS AND CREW SUPPORT

(TBD)

4.12 EXTRA-VEHICULAR ACTIVITY (EVA)

The module shall be equipped with TBD inflatable rescue spheres and TBD POS's to support emergency rescue.

4.13 INTERNAL VEHICULAR ACTIVITY (IVA)

(TBD)

4.14 HEALTH MAINTENANCE

The Health Maintenance functions will be incorporated in the Human Life Science Laboratory, launched 1-3 years after IOC.

4.15 FLUID MANAGEMENT

TBD vacuum lines shall be provided for experiments with a capability of TBD micron-liters/sec. TBD venting lines shall be provided for experiments with a TBD capability.

5.0 LOGISTICS MODULE

5.1 GENERAL REQUIREMENTS

The Logistics Module will be used to resupply the Space Station with all required consumable items. A Logistics Module will be scheduled to be transported to the Space Station Base every ninety (90) days and there exchanged with the previous, depleted Logistics Module. Each Logistics Module will have a design life of TBD flights.

The items carried aboard the Logistics Module will be of two types: Short-term consumables and longer-term consumables.

5.1.1 Short-Term Consumables

Short-term consumables include food, water, clothes, oxygen, nitrogen, CO_2-removing chemicals, propellants, personal equipment, station housekeeping items, and miscellaneous items. These short-term consumables will be brought up in such quantities as to assure a ninety-day supply for all crew members (see Table 5-1).

5.1.2 Longer-Term Consumables

Longer-term consumables will include new instruments and payloads, Space Station spares, OTV and TMS spares, payload spares, and items needed for resupply of payloads. The weight and volume capabilities for these longer-term consumables is presented in Table 5-2.

5.1.3 Return Capabilities

The Logistics Module will also be the repository into which will be stored for return to the ground TBD pounds/TBD cubic feet of processed materials; TBD pounds/TBD cubic feet of failed ORU's, obsolete equipment or payloads; TBD pounds/TBD cubic feet of Space Station trash; and TBD pounds/TBD cubic feet of waste.

5.1.4 Safe Haven

The Logistics Module will have the capability to function as a safe haven.

5.2 STRUCTURES

The Logistics Module will have both pressurized structure and unpressurized structure.

5.2.1 Pressurized Structure

The pressurized structure of the Logistics Module will share in the common structural heritage of the other Space Station modules.

5.2.2 Unpressurized Structure

An unpressurized structure will be constructed off the closed end. It will be the diameter of the pressurized module and TBD feet in length. This structure will support the water, oxygen, nitrogen, and propellant tankage.

5.3 MECHANISMS

Normal access to the pressurized portion of the Logistics Module will be through a single, axial berthing port.

5.4 ELECTRICAL POWER

The Logistics Module will require an average of TBD Kilowatts of electrical power (TBD kW peak power).

5.5 THERMAL

Thermal management of TBD Kilowatts is required.

5.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

The Logistics Module will be provided with an environment control and life support subsystem (ECLSS).

5.7 INFORMATION AND DATA

A console will be located in the Logistics Module for Station control.

5.8 COMMUNICATION AND TRACKING

TBD standard communications equipment will be located in the Logistics Module.

5.9 ATTITUDE AND ORBIT CONTROL

NOT APPLICABLE

5.10 PROPULSION

NOT APPLICABLE

5.11 CREW SYSTEMS AND CREW SUPPORT

The Logistics Module will contain the crew primary hygiene facilities. These facilities include a shower, waste management station, and hygiene console.

5.12 EXTRA-VEHICULAR ACTIVITY (EVA)

NOT APPLICABLE

5.13 INTERNAL VEHICULAR ACTIVITY (IVA)

NOT APPLICABLE

TABLE 5-1

LOGISTICS MODULE: SHORT-TERM CONSUMABLES

ITEM	WEIGHT (pounds)	VOLUME (Cubic Feet)
Food	TBD	TBD
Water	TBD	TBD
Oxygen	TBD	TBD
Nitrogen	TBD	TBD
Clothes	TBD	TBD
CO2-Removing Chemicals	TBD	TBD
Propellants	TBD	TBD
Personal Equipment, Station Housekeeping, Miscellaneous	TBD	TBD

TABLE 5-2

LOGISTICS MODULE: LONGER-TERM CONSUMABLES

ITEM	WEIGHT (pounds)	VOLUME (Cubic Feet)
New Instruments/Payloads	TBD	TBD
Space Station Spares	TBD	TBD
OTV and TMS Spares	TBD	TBD
Payload Resupply Items	TBD	TBD
Payload Spares	TBD	TBD

5.14 HEALTH MAINTENANCE

NOT APPLICABLE

5.15 FLUID MANAGEMENT

NOT APPLICABLE

6.0 SERVICING CAPABILITY

The Space Station shall have facilities to service or provide servicing support for:

- Teleoperator Maneuvering System (TMS) based at the Space Station;
- Satellites brought to the station by the TMS or serviced remotely (in-situ) by the TMS;
- Co-orbiting platform brought to the station or serviced in-situ;
- Payloads on the co-orbiting platform at the Space Station or in-situ;
- Payloads attached to the Space Station;
- Technology Development Missions such as the construction of large space structures;
- Orbital Transfer Vehicles (OTV's) based at the Space Station; and
- OTV payloads (assembly, checkout, and mating to the OTV).
- Satellites in GEO and other high energy orbits serviced in-situ by the TMS.

The servicing capability shall evolve during the life of the station as outlined in section 2.2 entitled Capability Evolution.

6.1 COMMON SERVICING FACILITIES

6.1.1 Berthing Truss

The Space Station shall provide a berthing truss, TBD feet in length, attached to the station which provides structural support for the elements of the servicing facility.

6.1.2 Remote Manipulator System (RMS)

The Space Station shall have a RMS which can be used for berthing the TMS, OTV's, satellites, and payloads brought to the station for servicing. The RMS shall be relocatable and shall have access to the berths for the TMS, OTV's, satellites, and payloads. The RMS shall also be used to change out modules and payloads and to assist in the assembly of structures.

6.1.3 Manned Maneuvering Unit (MMU)

The Space Station shall be equipped with two MMU's and two MMU Flight Support Systems (FSS's). Electrical power and propellant for the MMU's shall be provided by the Space Station.

6.1.4 Manipulator Foot Restraint (MFR)

The Space Station shall be equipped with a MFR, which attaches to the RMS and enables an EVA astronaut to perform maintenance on the TMS, OTV's and the satellites and payloads berthed at the station.

6.1.5 Modular Equipment Storage Assembly (MESA)

The Space Station shall be equipped with an MESA, which is a standard tool kit developed for the STS.

6.1.6 General Storage Area And Work Area

The Space Station shall provide an enclosed unpressurized storage area for the MMU's and FSS's, MFR and MESA, and a general purpose work area for the construction of large space structures. The dimensions of the work area are TBD.

6.1.7 External Work Site Monitoring And Control Station

An external work site monitoring and control station shall be provided in a pressurized module. The station functions shall include: control of berthing and handling equipment and of lighting, EVA communication, monitoring of proximity navigation, TV viewing of distant work and storage locations, control of liquid and gas transfer operations, and control of the TMS during proximity operations.

6.2 TELEOPERATOR MANEUVERING SYSTEM (TMS) SERVICING FACILITIES

6.2.1 Berthing Provisions

A hard interface shall be provided for berthing the TMS to the station. Provisions for resupply of TMS expendables and for electrical power shall be available at the berthing location. All sides of the vehicle shall be accessible for inspection and maintenance while it is berthed.

6.2.2 Berthing Corridor

The berthing corridor for the TMS shall have a cross section not less than the vehicle plus a TBD feet radial clearance in all directions.

6.2.3 Electrical Power

The Space Station shall be capable of providing TBD kW of electrical power to the TMS. Devices and operational constraints shall be adequate to preclude loss of or damage to either the TMS or the electrical system in case of a malfunction.

6.2.4 Propellant

The Space Station shall supply propellants to the TMS from tanks located at the station. The propellant is TBD. The tanks shall have a capacity of TBD fillings of the TMS tanks. (The capacity of the TMS tanks is TBD). Thermal control and micrometeoroid/debris protection shall be provided for the propellant tanks.

6.2.5 Pressurants

The Space Station shall provide pressurants for the TMS propulsion system at the berthing location. The type and quantities of pressurants are: TBD.

6.2.6 Checkout

The Space Station shall have the capability to checkout the TMS while it is berthed at the Station.

6.2.7 Hangar

The Space Station shall provide an unpressurized hangar which encloses the TMS berth. The hangar shall have a shielding effectiveness against micrometeroid/debris damage of TBD. Minimum clearance of TBD feet shall exist between the vehicle and the hangar walls so that EVA servicing can be performed within the hangar. The design of the hangar shall allow access by the RMS. The hangar shall have interior lighting.

6.2.8 Storage Area

The Space Station shall provide an enclosed unpressurized storage area adjacent to the TMS berth for the TMS mission kits (remote refueling tanker, remote servicing mechanism, dexterous manipulator/debris capture (TBD) and long-term orbital storage) and also for checkout equipment and spare ORU's for the TMS.

6.3 ORBITAL TRANSFER VEHICLE (OTV) SERVICING FACILITIES

6.3.1 Berthing Provisions

Two hard interfaces shall be provided for berthing OTV's to the Space Station. All sides of the OTV shall be accessable for inspection and maintenance while they are berthed.

6.3.2 Berthing Corridors

The berthing corridors for the OTV's shall have a cross section not less than the vehicle plus a TBD feet radial clearance in all directions.

6.3.3 Electrical Power

The Space Station shall be capable of providing TBD kW of electrical power to the OTV. Devices and operational constraints shall be adequate to preclude loss of or damage to either the OTV or the electrical system in case of malfunction.

6.3.4 Propellant Storage Facility

A facility (location TBD) will be provided for storage of OTV propellants. The facility will also have the capability of transferring propellants to/from the OTV, and from a ground based delivery system.

Propellants - Propellants and their quantities are TBD.

Pressurants - Pressurants and their quantities are TBD.

Interfaces - Standard propellant and pressurant transfer interfaces will be provided which are designed to comply with safety regulations and that preclude mating to the wrong propellant or pressurant connection.

Thermal Control - Provisions for thermal control will be provided for propellant conditioning.

Micrometeroid/Debris Protection - Design features will be incorporated to provide meteroid protection for the facility. Details TBD.

Propellant Acquisition - The facility will be capable of acquiring and transferring propellants and pressurants independent of the gravitational environment.

Fluid Quantity - The facility shall be capable of determining propellant and pressurant quantities in the storage system in the static mode and during the dynamic modes of resupply and OTV refueling.

Automatic Operation - The facility shall be capable of automatic operation with minimum crew functions. Time lines associated with transfer operations will be minimized.

Contamination Control - Provisions for propellant and fluid contaminants control shall be provided. Details TBD.

Fluid Dynamics Control - Motions and moments of less than TBD shall be imparted to the Space Station or interfacing elements as a result of fluid dynamic interactions or venting.

6.3.5 Checkout

The Space Station shall have the capability to checkout the OTV while it is berthed at the Station.

6.3.6 Hangar

The Space Station shall provide two hangars which enclose the two OTV berths. The hangers shall have a shielding effectiveness against micrometeroid/debris damage of TBD. Minimum clearance of TBD feet shall exist between the vehicle and the hangar walls so the EVA servicing can be performed within the hangar. The design of the hangars shall allow access by the RMS. The hangers shall have interior lighting.

6.3.7 Storage Area And Payload Assembly/Checkout Area

The Space Station shall provide an enclosed unpressurized storage area adjacent to the OTV berths for checkout equipment and spare ORU's for the OTV, and an area in which payloads for the OTV are assembled and checked-out before being mated to the OTV.

6.3.8 OTV/Payload Integration

The Space Station shall have the capability of assembling and checking out the complete OTV vehicle.

6.4 SATELLITE SERVICING FACILITIES

6.4.1 Berthing Provisions

A hard interface shall be provided for berthing satellites at the station. Provisions for resupply of satellite expendables and for electrical power shall be available at the berthing location. All sides of the satellite shall be accessable for inspection and maintenance while it is berthed.

6.4.2 Berthing Corridor

The berthing corridor for satellites shall have a cross section not less than the largest satellite to be berthed plus a TBD feet radial clearance in all directions.

6.4.3 Electrical Power

The Space Station shall be capable of providing TBD kW of electrical power at the satellite berth. Devices and operational constraints shall be adequate to preclude loss of or damage to either the satellite being serviced or the electrical system in case of a malfunction.

6.4.4 Expendable Fluids

The Space Station shall be capable of supplying expendable fluids to satellites from tanks located at or delivered to the station. The types and quantities of fluids are: TBD.

6.4.5 Pressurants

The Space Station shall provide pressurants to satellites at the berthing location from tanks located at the station. The types and quantities of pressurants are: TBD.

6.4.6 Checkout

The Space Station shall have the capability to checkout satellites while they are berthed at the station.

6.4.7 Hangar

The Space Station shall provide an unpressurized hangar which enclose the satellite servicing berthing area. The hangar shall have a shielding effectiveness against micrometeroid/debris damage of TBD. Minimum clearance of TBD feet shall exist between the satellite and the hangar walls so that EVA servicing can be performed within the hangar. The design of the hangar shall allow access by the RMS. The hangar shall have interior lighting.

6.4.8 Storage Area

The Space Station shall provide an enclosed unpressurized storage area adjacent to the satellite berth for checkout equipment and spare ORU's for satellites that will be serviced at the station.

7.0 PLATFORMS

7.1 GENERAL REQUIREMENTS

The co-orbiting and polar platforms in the Space Station system are to be derived from components of the Space Station to the extent technically feasible and economically beneficial. This includes the Utility Module with performance parameters appropriate to meet the respective platform requirements for mounting locations, view orientations and attitude/stability, power, information and data subsystem support, thermal control and communications. It also includes the use of common structural elements and mechanisms. The redundancy plan for the platform shall be developed based upon the servicing environment of the polar platform.

7.2 STRUCTURES

The structure of the co-orbiting platform shall be developed by combining a Utility Module with TBD units of the Operations Module primary structure (see Appendix C, Section 4.2). The structure shall have TBD stationary and TBD rotating instrument mounting ports. The port selection from those available on the standard structure segment to be assembled shall provide earth, solar and stellar viewing. The secondary structure shall not be pressurized. It shall be designed for maintenance and instrument replacement by TMS or EVA from the Space Station, or STS.

The configuration of the polar platform shall be developed from a Utility Module combined with an instrument mounting structure suitable to meet the integrated viewing and volume requirements of the instruments and the required attitude and stability as defined in Section 6.9.* The structure design shall consider the Utility Module and instrument dynamic coupling effects and the

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*The instrument structure is not included within the scope of the Space Station System.

thermal environment in order for the platform to meet the performance requirements specified in section 3.2. The instrument mounting structure shall be designed to accommodate both interchangeability of instruments and the addition of instruments in several stages of mission development. The number of instruments and their viewing requirements in each stage is TBD. The evolutionary structure concept shall be designed with consideration of the STS polar payload launch capability and on-orbit servicing capability. The servicing of the platforms will be performed primarily in-situ by TMS. Secondary servicing of the Co-Orbiter Platform will be performed by EVA from the Space Station or the Orbiter. Secondary servicing of the Polar Platform will be performed by EVA from the Orbiter.

7.3 MECHANISMS

7.3.1 Instrument Pointing System

An instrument pointing system (IPS) is required between the co-orbiting platform structure mounting port and the instrument mounting surface when the pointing accuracy and stability, or knowledge of the actual pointing cannot be met directly by the platform. The IPS shall be designed to provide accurate pointing to earth, solar or stellar viewing with the following accuracy and stability requirements.

Viewing	Attitude (Degrees)	Stability (Degrees/Second)
Earth	TBD	TBD
Solar	TBD	TBD
Stellar	TBD	TBD

The instrument weight and C.G. relationship to the mounting surface, and the mounting surface area required to be accommodated by the instrument pointing system is TBD.

The thermal interface of the instrument mounting surface is TBD.

The design of the instrument mounting surface shall allow a TBD impulse without degrading its attitude pointing performance.

The operation and system control of the IPS will be accomplished via the Information and Data Subsystem computer.

7.3.2 Berthing Mechanism

The co-orbiting platform structure shall be equipped with a berthing mechanism for the TMS for orbital maneuvering by the TMS and a berthing mechanism for servicing at the Space Station.

7.4 ELECTRICAL POWER

The electrical power system shall provide TBD average power to the co-orbiter and TBD average power to the polar platform. The power generation system shall be designed to provide the required power for the polar platform to be in a TBD local time daylight equator crossing. The power generation system shall be designed in conjunction with instrument cooler space viewing requirements that are TBD.

7.5 THERMAL

The central thermal control system shall not be used for the instrument carriers. Separate thermal control shall be provided for the Utility Module. The instrument carriers shall be designed for independent thermal control in conjunction with the instrument thermal performance requirements.

7.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

NOT APPLICABLE

7.7 INFORMATION AND DATA

The information and data system shall be designed to accommodate the data rates in section 3.3.4 from a quantity of instruments specified in Section 7.2. In addition, the polar platform data system shall be capable of throughputting to the communications system, data from the data storage system, science data processed on-board for real time direct broadcast to customers, and ground truth/ancillary data received and processed by the data collection and location system. The data storage system is also required for the co-orbiter.

A TBD block of the processing computer memory shall be provided for processing instrument science data with software provided by the customer to generate the direct broadcast output.

The data system shall be designed to facilitate full data collection and retrieval of global data with a TBD data rate and TBD minutes of TBD MBPS local area data when the real time transmission of data through TDRSS is not possible.

7.8 COMMUNICATIONS AND TRACKING

The co-orbiting platform shall have the following additional capability to the TDRSS and GPS links of the basic Utility Module:

a. Transmission of data to the Space Station for interactive operation of platform experiments from the Space Station. The maximum data rate for this link is TBD.

b. Receipt of commands from the Space Station for operations in the interactive mode.

The polar platform shall have the following additional capability to the TDRSS and GPS links of the basic Utility Module.

a. Transmit science data directly to the ground at a maximum rate of TBD.

The communications and tracking system shall be designed to generate orbital position with and without a GPS to the following accuracies:

	Accuracy (Meters)	
	With GPS	Without GPS
in-track	TBD	TBD
cross-track	TBD	TBD
altitude	TBD	TBD

7.9 ATTITUDE AND ONBOARD FLIGHT CONTROL

The attitude control system in conjunction with the platform structural/thermal design and the use of instrument pointing systems shall have the capability required to meet the instrument pointing and stability requirements specified in section 3.2. It shall have suitable sensors that will provide the information required to calculate the actual attitude to the accuracies of TBD.

The attitude and orbit control system for the co-orbiter shall provide the following capabilities:

a. Position and maintain the co-orbiting relationship with the core station within TBD miles line of sight range and coplanar within TBD degrees.

b. Change the phase relationship with the core station beyond that which provides line of sight communications in order to operate effectively as a free flyer.

c. Provide a capability to rotate the spacecraft 180° in yaw if required for thermal control when the sun crosses the orbit plane.

d. Allow for refueling of expendables.

The attitude and orbit control system for the polar platform shall provide the capability to maintain the orbit altitude within the range specified in section 3.1 and adjust the orbit plane inclination to retain the sun Beta angle within TBD degrees max. It shall provide the initial acquisition capture capability after deployment by the STS and provide the necessary attitude control in conjunction with the propulsion system design.

The attitude and orbit control system shall be capable of supporting orbital maneuvers performed by the TMS which is an alternate capability to the primary on-board propulsion system.

7.10 PROPULSION

The polar platform shall be provided with a propulsion capability that can transfer the platform to the required altitude from the Shuttle deployment altitude or return it from on-orbit altitude to Shuttle altitudes. The design of the propulsion subsystem shall take into account power system design limitations with respect to dynamic characteristics during the orbit maneuvers.* The system shall be designed for refueling of expendables.

7.11 CREW SYSTEMS AND CREW SUPPORT

NOT APPLICABLE

7.12 EXTRA-VEHICULAR ACTIVITY (EVA)

NOT APPLICABLE

7.13 INTERNAL VEHICULAR ACTIVITY (IVA)

NOT APPLICABLE

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*It shall consider all appendages that may interfere with propulsion performance and take into account center of gravity location variations as a function of configuration evolution.

7.14 HEALTH MAINTENANCE

NOT APPLICABLE

7.15 FLUID MANAGEMENT

The fluid management system will be utilized as applicable.

8.0 GROUND SUPPORT SYSTEMS

8.1 MISSION SUPPORT SYSTEM

8.1.1 General Requirements

A system shall be provided to support the activation and operation of the Space Station during flight operation. This system shall provide the necessary equipment to train flight and ground crews in the normal operation and contingency situations of the Space Station; to receive, decode, display, and record Space Station data; to communicate with the Space Station system; and to support the Space Station with data and commands as required to perform the mission. In addition, trained and qualified personnel shall be provided to support the Space Station during operations.

8.1.2 Training and Simulation Subsystem

(TBD)

8.1.3 Flight Support System

(TBD)

8.1.4 Mission Data Support System

(TBD)

8.2 MISSION PREPARATION AND RECOVERY SYSTEM

(TBD)

8.2.1 General Requirements

A system shall be provided to support the Space Station elements during ground operations prior to launch of the initial elements and to recover and recycle the elements through the necessary operations prior to reuse of the element(s).

8.3 CUSTOMER SUPPORT SUBSYSTEM

8.3.1 General Requirements

A system shall be provided to support the customer during the preparation of the payloads/experiments for flight, to support the payloads/experiments during flight operations by providing communications between the customer and the Space Station, providing a port(s) or access to the Space Station Information Data System for the customer during payloads/experiments operation, and to recover the payloads/experiments post-mission.

8.3.2 Customer Prelaunch Verification And Preparation Subsystem

(TBD)

8.3.3 Customer Mission Support Subsystem

(TBD)

8.3.4 Customer Post-Mission Support Subsystem

(TBD)

9.0 ORBITER BERTHING EQUIPMENT

9.1 GENERAL REQUIREMENTS

The Space Station shall provide equipment which allows the shuttle to berth with the station and transfer crew and material in a pressurized environment. This equipment shall include TBD.

9.2 STRUCTURES

(TBD)

9.3 MECHANISMS

Berthing hatches shall be sized for a TBD inch diameter opening.

All hatches shall be capable of operation from either side of the hatch.

Capability for equalization of pressure across the hatch shall be provided.

All hatches shall close in the direction of positive pressure differential.

All hatches shall be provided with hinge linkages to control hatch motion.

Areas into which hatches open shall be designed so that the full-open position of the hatch does not block crew passage.

Berthing equipment shall meet the following requirements:

Berthing systems shall be androgynous (both sides the same) except for certain specialized umbilical interconnects (i.e., modules with identical berthing systems may be berthed together).

Berthing design contact conditions are as follows:

Condition	Value
Axial closing velocity	TBD
Lateral velocity	TBD
Angular velocity	TBD
Lateral misalignment	TBD
Angular misalignment	TBD

The above data are total values relative to the berthing interface.

9.4 ELECTRICAL POWER

(TBD)

9.5 THERMAL

(TBD)

9.6 ENVIRONMENTAL CONTROL AND LIFE SUPPORT (ECLS)

(TBD)

9.7 INFORMATION AND DATA MANAGEMENT

(TBD)

9.8 COMMUNICATIONS AND TRACKING

(TBD)

9.9 ATTITUDE AND ONBOARD FLIGHT CONTROL

(TBD)

9.10 PROPULSION

(TBD)

9.11 CREWS SYSTEMS AND CREW SUPPORT

(TBD)

9.12 EXTRA VEHICULAR ACTIVITY (EVA)

(TBD)

9.13 INTERNAL VEHICULAR ACTIVITY (IVA)

(TBD)

9.14 HEALTH MAINTENANCE

(TBD)

9.15 FLUID MANAGEMENT

(TBD)

APPENDIX D

DEFINITIONS

APPENDIX D

DEFINITIONS

ARTIFICIAL INTELLIGENCE: A discipline which attempts to simulate or duplicate the efficient problem-solving capabilities of humans.

AUTONOMY: The ability to function as an independent unit or element, over an extended period of time, performing a variety of actions necessary to achieve pre-designated objectives, while responding to stimuli produced by integrally-contained sensors.

AUTOMATION: The ability to carry out a pre-designated function or series of actions, after being initiated by an external stimulus, without the necessity of further human intervention.

BASE: A core of modules including facilities for docking, control, and human habitation.

BERTHING: The joining in space of two spacecraft or spacecraft modules by maneuvering one into contact with the other at the berthing interface and then latching the berthing mechanism.

ELEMENT: Any module, platform, or free flyer which is dependent upon the Space Station system for its long-term operation.

FACTORS OF SAFETY: Assumed multiplicative constants applied to actual or limit loads to account for uncertainties in load definition, materials properties, dimensional discrepancies, etc.

FREE FLYER: Any free-flying, unmanned satellite which is serviced by or otherwise dependent upon the Space Station system.

MARGIN OF SAFETY: Margin of Safety =

$$\frac{(\text{Allowable Load}\qquad)}{(\text{Actual Load x Factor of Safety})} - 1$$

MECHANISMS: Devices consisting of two or more parts which move relative to one another to effect a different configuration of the parts. Mechanisms often involve many disciplines such as electrical, mechanical, thermal, optical, and pyrotechnic.

MODULE: An attached Space Station element which provides a unique or common function for system operations.

PLATFORM: An unmanned, orbiting, multi-use structure capable of supplying limited utilities to changeable payloads and dependent upon the Space Station system for its long-term operation.

PRIMARY STRUCTURE: That structure which reacts to or transmits loads developed by the entire Space Station system (e.g., pressure shells of modules and the structural elements of the mechanism's connecting modules).

ROBOTICS: The technology by which machines perform all aspects of an action, including sensing, analysis, planning, direction/control, and effecting/manipulation, with human supervision.

SECONDARY STRUCTURE: That structure which reacts to loads created by its own mass, by attached subsystems, and by crew activity and transmits this load to the primary structure (e.g., walls, floors, and partitions within modules, and both interior and exterior equipment mounts).

SPACE STATION: A totality of manned and unmanned, Earth-orbiting interdependent elements.

SUPPORT: Ground or space-based operations and equipment which interact with the Space Station.

TELEOPERATION: Remote manipulation in which humans are responsible for generating control signals.

TELEPRESENCE: The ability to transfer a human's sensory perceptions (e.g., visual, tactile, etc.) to a remote site.

TRANSPORT STRUCTURE: That structure provided as primarily temporary support for secondary structures and equipment loads during pre-launch, launch, entry, and landing and may be removed and stowed, used for alternate purposes on orbit or returned to Earth until needed. Transport structure transmits loads to the primary structure within the modules or on the outside of modules.

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SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 4

ADVANCED DEVELOPMENT PROGRAM

Prepared By The:

SPACE STATION TASK FORCE

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SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 4

ADVANCED DEVELOPMENT PROGRAM

Approved By:

JOHN D. HODGE
Director
Space Station Task Force

PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
BOOK 6	SYSTEM OPERATIONS
BOOK 7	PROGRAM PLAN

BOOK 4
SPACE STATION ADVANCED DEVELOPMENT PROGRAM

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1.0 INTRODUCTION

After the successful development of the Space Transportation System, NASA is proposing that a Space Station be the next, major U.S. activity in space. Such a Space Station would be implemented over a period of 10-15 years beginning with the deployment of the initial capability in the early 1990's.

The Space Station's desired operational characteristics, as defined by the Space Station Task Force (SSTF), can be summarized to include indefinite on-orbit presence, accessibility via the Shuttle, permanently-manned occupancy, the ability to be maintained and repaired in space, built-in growth potential, and user accommodating. These characteristics are being used to define technical design requirements and criteria for the system. Assessments of these requirements by NASA's Space Station Technology Steering Committee (SSTSC), the SSTF Concept Development Group, and representatives from industry have led to the conclusion that the current state-of-the-art technology in selected disciplines is inadequate to permit building the desired Space Station without compromising some of its desired operational characteristics. However, it is felt that appropriate technological advancements will be forthcoming with proper emphasis and investment. Therefore, technology will play a preeminent role in determining both the initial and future space station capability and utilization.

The challenge posed by the Space Station is to develop key technologies that are critical to the initial Space Station configuration without obviating the application of advanced technologies in the evolutionary growth elements of the system. Evolution implies not only growth of the physical plant, but also increases in system performance, capability, and complexity.

The proposed Space Station phase C/D start date in FY 1987 allows several years in which to mature new technologies for application in the initial system and, subsequently, in its evolutionary growth configurations. The approach being taken by NASA to develop and demonstrate technology for the Space Station builds upon the Agency's strong generic research and technology (R&T) base program. Through assessments of the R&T program, high potential technologies have been identified that are relevant to a Space Station application and have the potential to enhance or enable the desired operational system. From these, specific technologies are being selected for advanced development based on their potential and maturation forecast. In this context, advanced development implies a process whereby generic technologies are focused to a Space Station application and matured to a brassboard/prototype level in order to demonstrate their feasibility, establish their performance, and quantify the risk (cost and schedule) associated with their inclusion in the Space Station development phase.

Accordingly, a programmatic distinction will be made in this document between the generic Space Research and Technology Program, which consists of the base R&T activities, and the Advanced Development Program, which provides for focusing generic technologies to a Space Station application, building and integrating prototype components into subsystems for demonstration in ground based test bed facilities, and conducting flight experiments using the Shuttle as necessary. It must be emphasized that both programs represent activities in the technology development process and that the Advanced Development Program emanates from and builds upon the generic base.

The Office of Aeronautics and Space Technology (OAST) has adopted a widely accepted technique for describing the technology development process whereby progressively increasing levels of maturity are used to depict the state of development. This technique also facilitates the partitioning of the process into the traditional activity categories of research, generic technology, focused or applied technology, and prototypical engineering. These levels of technology maturity are as follows:

<u>Level 1</u>: Basic principals observed and reported.

<u>Level 2</u>: Conceptual design formulated.

<u>Level 3</u>: Conceptual design tested analytically or experimentally.

<u>Level 4</u>: Critical function breadboard demonstration.

<u>Level 5</u>: Component or brassboard model tested in relevant environment.

<u>Level 6</u>: Prototype or engineering model tested in relevant environment.

Level 7: Engineering model tested in space.

Level 8: Baselined into production design.

The purpose of this document is to describe the planning and implementation activities associated with developing technology for the Space Station. No attempt will be made to describe the generic R&T base in detail. However, it must be understood that all the technologies discussed derive from the R&T base. Therefore, the emphasis of this document will be the Space Station Advanced Development Program (ADP) which is to be funded under the aegis of the Space Station Program.

This document is organized to describe the elements of the ADP, the management approach and organizational relationships, technology by theme and technical discipline, test beds, and flight experiments. Detailed discipline activity plans which integrate across focused technology, prototype technology, test beds, and flight experiments, will augment this document in the form of appendices. These detailed plans will be updated yearly to reflect accomplishments, funding levels, and any changes in emphasis.

2.0 PROGRAM ELEMENT DESCRIPTION

In anticipation of a Space Station initiative and in recognition of the role that technology might play in its design, NASA management commissioned the Space Station Technology Steering Committee (SSTSC) in the Fall of 1981 to provide guidance for the initiation and implementation of technology development programs. Using guidelines similar to the operational characteristics discussed in Section 1.0 the SSTSC formulated the following set of objectives to guide their activities:

- Establish the desired level of technology to be used in the initial design and operation of an evolutionary, long-life Space Station and the longer term technology to be used for later application for improved capabilities. Initial technology should be available by approximately 1986 to support a Space Station launch in 1990.

- Assess the level of technology that will be available from the current base R&T program which will be applicable to a Space Station.

- Plan, recommend, and monitor a program to move the current technology to the level stated above.

- Identify, evaluate, and recommend opportunities to utilize the Space Station as an R&T facility.

The SSTSC responded to their task in admirable fashion. Their assessments, including industry participation at the Williamsburg Technology Conference in March of 1983, resulted in a set of recommended advanced technologies which should be matured to support the initial Space Station and its evolutionary configurations. In addition to providing scope and direction to the generic space research and technology (R&T) program, these recommendations are now being used to formulate the activities of the Advanced Development Program's key elements: focused technology, prototype technology, test beds, and flight experiments.

2.1 GENERIC TECHNOLOGY BASE

NASA's space R&T program provides and maintains a generic technology base to adequately support current activities and enhance or enable future activities involved in the exploration and exploitation of space. This activity embraces all of the technical disciplines and areas of systems research associated with space to continually provide a wellspring of ideas for advanced concepts and applications.

Within NASA, the Office of Aeronautics and Space Technology (OAST) has the primary responsibility for conducting the space R&T program including programmatic emphasis to advance the generic base to support a permanent human presence in space via an optimally designed Space Station (i.e., a system embracing, as practical, the cutting edge of advanced technologies). Other NASA offices (e.g., Space Science and Applications, Space Flight, and Space Tracking and Data Systems) also conduct advanced technology application activities that contribute to and strengthen the Space R&T Program.

In summary, the space R&T program maintains a base of generic activities from which specific new technologies are being selected for advancement based upon their potential for enhancing the design and implementation of the Space Station. These technologies will be identified and described in the following sections of this document.

2.2 FOCUSED TECHNOLOGY

The objective of the Advanced Development Program is to provide a portfolio of new technologies that can be used in the design of the Space Station. A set of these potential technologies at various levels of early maturity have been identified in the generic R&T base. However, without continued funding and emphasis, it is possible that many of these will not make the "gate" (i.e., be factored into the initial or subsequent designs of the Space Station). There are several reasons why this may happen. First, the technologies within the generic base activity do not normally reach levels of maturity that clearly establish feasibility and risk for a specific application. Lack of funding and clear requirements are common impediments. Second, due to a lack of demonstrated maturity, the system designer is driven to select technology from the existing state-of-the-art because program timelines cannot accommodate schedules for proof-of-concept demonstrations or because there is an unwillingness to accept the risk associated with relative but immature technology. A third constraint hindering the transfer and use of advanced technology is often associated with the lack of "technology awareness" by system developers.

Therefore, the initial activity element of the Advanced Development Program is to ensure that a clear and proper application focus is provided to the generic R&T base program and that the necessary funding is provided to continue technology development through demonstration at the breadboard level. These activities constitute "focused technology".

2.3 PROTOTYPE TECHNOLOGY

Once the generic base technologies have been focused to the Space Station application and their maturity has been demonstrated for feasibility by the technologists in the laboratory, decisions to continue the development process into prototype components and subsystems can be made. These decisions will be based upon assessments of the maturity that individual technologies must achieve to become viable options for application in the design of the Space Station system. These assessments will include consideration of technical complexity, development risk, potential benefit, and perceived need.

It is through this element of the Advanced Development Program that advocacy and funding will be provided for developing prototypical hardware that embodies the advanced technologies. Once developed, this hardware will be integrated into subsystems and cycled into dedicated test beds for final test and evaluation. It is through the joint participation of technologists and system developers that the transfer of technology to the Space Station program will occur or at least be facilitated.

2.4 TEST BEDS

As previously stated, the prime objective of the Advanced Development Program is to advance the state-of-the-art technology to provide greater opportunities to enhance system performance, reduce life-cycle costs, and facilitate evolutionary changes to the operational system as desired. Fundamental to the success of this program are plans to implement general test bed capabilities in which new technologies, techniques, and approaches can be tested at the brassboard or prototype level of development. The general aspect is critical to the test beds because they must provide sufficient flexibility to accommodate a variety of technical approaches throughout the life of the Space Station program.

It is now planned that the test beds will be implemented along major Space Station subsystem disciplines. The initial test beds include: Data Management System; Environmental Control and Life Support System; Power System, Thermal System; Altitude Control and Stabilization System; Auxiliary Propulsion System; and Space Operations Mechanisms. Other test beds will be developed as appropriate.

Management responsibility for each of the test bed activities will be assigned to individual NASA Field Centers recognizing that specific elements of each test bed capability may reside at different locations. In planning, coordinating, and implementing their respective program, these Centers will be responsible for enlisting the participation and support of other NASA centers based upon expertise and related activities to ensure that a smooth transition occurs (i.e., technology transfer).

2.5 FLIGHT EXPERIMENTS

Although the test bed approach will be primarily manifested in ground-based facilities, the need for selected flight experiments and demonstrations in the space environment using the Shuttle is recognized and will be implemented as part of the Advanced Development Program.

The purpose of this activity is to use the unique space environment provided by the Space Shuttle to validate the performance of critical components and subsystems which cannot be validated in ground tests in order to verify and quantify calculated performance, to identify unforeseen anomalies, and to update engineering design criteria. It will also demonstrate techniques, sensors, tools, and procedures required for Space Station control, maintenance, and repair and servicing operations. The approach will be to identify candidate flight experiments and demonstrations, develop integrated plans including resources and schedules, and coordinate with other NASA elements conducting Shuttle flight experiment programs. Candidate Space Shuttle flight experiments include environmental interaction plasma effects, contamination, cryogenic fluid management, thermal systems, and environment control life support system hardware.

3.0 MANAGEMENT APPROACH

The management of the Advanced Development Program will be implemented through a Space Station Program Directive. The nature of this directive will be described below. It will address only the activities falling under the funding cognizance of the Space Station program; it will not apply to the generic base R&T activities.

3.1 PURPOSE

The purpose of the directive will be to implement the Space Station Advanced Development Program in the near-term and to provide the guidelines to accommodate potential future changes to the program management structure. The Advanced Development Program is the primary mechanism by which advanced technologies will be developed to become viable options for application in the initial and evolutionary Space Station.

3.2 OBJECTIVES

The objectives of the Advanced Development Program are consistent with and support the Agency's goals for planning, implementing, and operating a Space Station system. The program serves as the umbrella for all technology development activities starting with the focusing of generic technologies to the Space Station application, development of prototype technology components/subsystems, their integration and testing in discipline test beds, and flight experiments and demonstrations as required. The specific program objectives are:

- To provide advanced technology alternatives for the initial and evolutionary Space Station which optimize the system's functional characteristics in terms of performance, cost, and utilization.
- To develop methodologies for enhancing and facilitating the transfer of new and advanced technologies from technologists to system planners/developers.
- To interface with industry to establish "informed" contractor teams to support the development and operational phases of the Space Station program.

3.3 SCOPE

Building upon the generic R&T base, the Advanced Development Program includes the present and planned focused technology tasks, development of prototype hardware, development and implementation of system test beds, and in-space flight experiments required to demonstrate and verify technologies in areas where the space environment is critical to their performance.

The technology expertise of both NASA and industry will be incorporated. Industry involvement will occur in a dual manner: as contractors supporting NASA's focused and prototype technology activities and as contractors performing portions of the Phase B System Definition Procurements. NASA centers will implement and operate test beds and will assure their availability and use in testing and evaluation of advanced technologies and new techniques.

The major disciplines for technology development are:

- Systems and Operations;
- Data Management;
- Environmental Control and Life Support;
- Power;
- Thermal;
- Human Productivity;
- Auxiliary Propulsion;
- Attitude Control and Stabilization;
- Structures and Mechanisms; and
- Communications.

The initial discipline test beds are:

- Data Management System;
- Environmental Control and Life Support System;

- Power System;
- Thermal System;
- Space Operations Mechanisms;
- Attitude Control and Stabalization System; and
- Auxiliary Propulsion System.

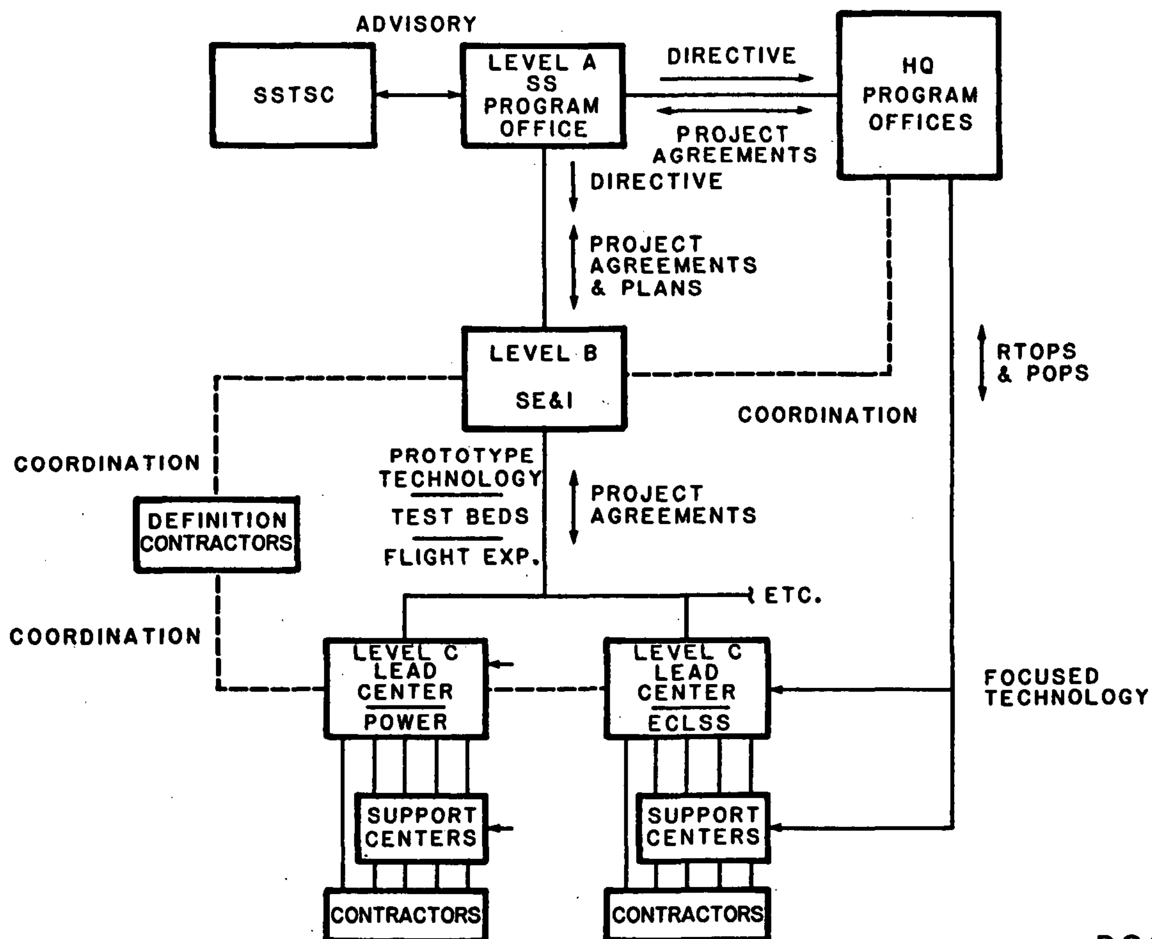
3.4 MANAGEMENT RELATIONSHIPS

The management relationships and key functions for implementing and controlling the Advanced Development Program are depicted in Figure 3.1. In this figure, Level A is assumed to be the Headquarters Space Station Program Office. The Level B Program Office will be located at a NASA Center and will include the Systems Engineering and Integration (SE&I) function, i.e., overall technical integration. The advanced development lead centers are shown at Level C with their supporting team members.

The Advanced Development Program will be formally initiated by Level A through the issuance of a Program Directive to the Level C centers through the Level B SE&I. The directive will call for program plans, by technical discipline, which are integrated across focused technology, prototype technology, test beds, and flight experiments. These plans will identify activities to be pursued for both the initial and evolutionary Space Station, funding requirements, schedules, major decision points, and other negotiable items. Approval of these plans by Level A will constitute a project agreement. Although the plans will be multi-year in nature, the proposed operating year activities will be reviewed and approved annually.

Inasmuch as focused technology builds upon the generic R & T base, the Center(s) performing the generic activities will be responsible for conducting the focused activities. Therefore, as depicted in Figure 3-1, agreements will be negotiated with the appropriate Headquarters Offices for the conduct of this work through established mechanisms (i.e., RTOP's and POP's). Funding for the remaining program elements (prototype technology, test beds, and flight experiments) will be made directly to the Level C lead centers. All funding distributions will be based upon approved program plans.

FIGURE 3-1
SPACE STATION PROGRAM ADVANCED DEVELOPMENT PROGRAM MANAGEMENT RELATIONSHIPS



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The Space Station Technology Steering committee (SSTSC) will serve as an advisory group to the SSTF. The technology development plans currently being prepared by the SSTSC in each of the discipline areas address focused technology, prototype technology, test beds, and flight experiments. In the near term, these plans will provide a starting point for the Level C Centers in preparing their initial Project Agreements and developing their implementation plans.

3.5 SCHEDULE

The Advanced Development Program is designed to support the initial and evolutionary Space Station. As such, the program must logically fit into and provide inputs to the overall Space Station Plan.

3.6 FUNDING RESOURCES

Funding profiles for the Advanced Development Program will be included in this document as an appendix. Detailed allocations by technical discipline will appear as part of the discipline plans, also to be included as appendices and updated on a yearly basis.

4.0 TECHNOLOGY THEMES

4.1 THEME CONCEPT/DEFINITION

In developing a Space Station technology program, there was early recognition that inseparable relationships exist between discrete discipline technologies. Life cycle cost and evolutionary growth capability form a common focus that relate individual technologies at the system level and within and among the disciplines. In addition, strong technical synergisms exist among certain discipline technology combinations that are clearly dominant drivers of performance and overall system cost. In some cases, the technical relationship is so strong that an element of one discipline technology is enabling to another discipline. For example, exact knowledge of the dynamics of low-frequency, flexible structures is critical not only to the performance but also to the stability envelope of the control system.

In order to better describe discipline technology interrelationships and identify cost and performance advantages at the system level, technology themes have been established. The themes delineate cost, performance, and operational leverage for utilization of common resources, similarity of function, integration of discrete disciplines, and optimization at the system level. They provide a description of technology from an overall perspective and are the mechanism to foster communication across disciplinary lines.

Since there are common threads of technology that cut across all disciplines (e.g., automation), it must be recognized that the themes themselves are strongly synergistic and highly interdependent.

4.2 THEME DESCRIPTIONS

This section identifies the initial set of technology themes that have emerged from Space Station technology planning and describes each one individually. The initial list of primary technology themes includes the following:

- Advanced information systems;
- Automation/autonomy;

- Human capability;
- *operations;*
- Evolutionary attitude control and stabilization;
- Energy management; and
- Integrated hydrogen/oxygen systems.

4.2.1 Advanced Information Systems

Since virtually every element of the Space Station system depends on a data system, its capability and configuration are critical elements. It is the key technology that will implement onboard autonomy and automation and provide the desired evolutionary growth capability for both physical size and technological improvement.

This theme focuses on the capacity, reliability, speed, and architecture of the data system as the primary support and interfacing function for all elements of the Space Station system.

An integrated advanced information system will be needed to provide control and management of system and subsystem functions, payloads, and remote operations. It must be able to monitor and analyze data, communicate among the subsystems, and distribute vital information throughout the data system network. It must also provide system reliability through fault-tolerant hardware and software to enable automation and support the variety of envisioned mission applications. Advanced data systems architecture and components will be developed for on-board and ground information acquisition, processing, distribution, and storage. Adaptive data networking with multiple link communication and distributed information system elements will provide for evolutionary growth. Advanced fiber optic bus and optical disk storage concepts will be explored to provide an onboard capability to handle and process high-speed, high-capacity information. Technology in advanced, fault-tolerant computers and automated, self-test software with fault detection and isolation will be developed for highly reliable, automated system operation.

Associated communication technology includes crew voice communications and conferencing, voice recognition and synthesis, public address, closed-circuit television, and crew entertainment. Required external communication links encompass the Shuttle orbiter, orbital transfer vehicles, teleoperators, data relay satellites, global positioning satellites, astronauts in extravehicular activity, and free-flying satellites. These communication and tracking needs imply technology requirements for full spherical coverage, minimal interference, wide bandwidth, frequency conservation, vicinity operations, and traffic control.

4.2.2 Automation/Autonomy

The automation/autonomy theme cuts across virtually every aspect of Space Station technology and has the maximum potential leverage on system and subsystem growth and capability as well as on life cycle cost throughout the evolutionary Space Station missions.

This technology will be pursued at both the system and discipline levels to establish overall automation architecture and to implement cost-effective levels of automation and autonomy within and among the subsystems. Since the data system will be the primary vehicle for achieving automation and autonomy, its capacity, speed, fault tolerance, and overall capability is critical to successful implementation. The on-board information system and distributed network must be configured to achieve initial levels of automation and autonomy and be adaptable to accommodate increased levels during evolution.

Automation/autonomy within the Space Station System is of particular interest in the area of life cycle costs. Present space systems have heavy human involvement in ground monitoring and operation at substantial, continuing operational costs. Furthermore, evolutionary growth in levels of Space Station performance and technological complexity requires that the crew assume a greater supervisory role in an automated system, thus making the system autonomous. Automation/autonomy is further needed to provide an extended operational lifetime (approximately 20 years) and to increase the versatility of the Space Station in terms of its adaptability to program/mission changes during development and its modularity for evolutionary growth.

Transition from human-managed, computer-aided (partly automated) space systems to human-supervised, computer-managed (autonomous) space systems will require a high degree of automation in observation, effort, and decision-making. Automation technology in observation includes signal detection, smart sensors, remote imaging, and computer vision. Automation technology effort includes manipulators, effectors, and motor control. Automation technology in decision-making (hence, autonomy) includes computer sciences, fault detection and isolation, adaptive networks, and expert systems.

An autonomous Space Station system will further require hardware and software technologies for hierarchical control of decision-making, fault management with self-diagnosis, repair and recovery capability, autonomous system architecture, machine intelligence, and human interface with intelligent systems.

4.2.3 Human Capability

Man's presence in space will require a wide variety of intravehicular activities (IVA) and extravehicular activities (EVA) including construction and assembly, maintenance, satellite and Orbital Transfer Vehicle (OTV) servicing, and mission-unique tasks. Advanced technology is being developed in life support, human factors, and automation, while efforts are underway to identify human capabilities and needs within automated space systems over extended periods. Life support technology will provide for the physiological health of humans during long-term occupancy in space. This technology will address environmental habitability, including noise and vibration aspects, and closed-loop regenerative life support systems for water reclamation and air revitalization.

The human factors effort will utilize simulators and analytical modeling to determine allocation of functions to humans and machines and the human interface with intelligent computer systems for optimal productivity. This effort will also develop controls and display technology for crew and work stations and design guidelines for crew psychological health, job aids, and procedures for in-space operations. EVA technology must be advanced in several areas such as greater spacesuit mobility and convenience of use (perhaps through higher suit pressure), tools, portable life support systems, and human performance. The automation technology effort will explore automated system concepts to optimize and/or enhance human capabilities in space. Technology will be developed for visual and tactile sensory feedback in teleoperator systems that will allow humans to perform tasks at a distance. Methodology and simulation capabilities will be established to enable development of teleoperations with increasing visual sense and dexterity. Advanced teleoperation technology will include control algorithms, sensors, end effectors, manipulator combinations, even multi-arms. Highly versatile teleoperations will approach the ability to both remotely sense and effect the environment with the versatility of humans; that is, telepresence. The hybrid, manual-machine control provided by teleoperation technology will be a significant element in the development of autonomous robotics mechanisms and systems.

4.2.4 Operations

Space Station operations will be characterized by reduced cost and increased use of man's capability in space. This will be achieved through philosophical, programmatic, and technological developments that reduce the number and cost of ground support personnel and take advantage of the unique ability of human involvement in on-board operations.

Previous manned programs required large ground crews during pre-launch, launch, and on-orbit operational phases. Early development of computer simulations at system and subsystem levels will lead to better understanding of hardware and software characteristics and interfaces. This knowledge will reduce the complexity and number of problems encountered during system assembly, integration, and checkout. The Space Station will be Shuttle-launched and Shuttle-tended, obviously allowing a cost savings over previous non-Shuttle-launched missions. On-orbit savings will be achieved by advanced automation of ground monitoring functions, reduced level of real-time monitoring, and increased reliance on the crew to schedule and structure crew activities. All of these changes will allow a dramatic decrease in ground personnel and cost.

Man's ability to function in space will also be enhanced. In addition to decoupling most of the crew activity from ground control, crew productivity will be increased by better utilization of crew time and augmentation of crew capability. Crew time will be better used by implementing technologies that minimize the crew workload for management of overhead activities and emphasize mission activities such as satellite servicing, construction, and experiment operations. Crew capability will be enhanced by the experience gained from long-duration, on-orbit operations and by technological developments in the areas of maintenance tools, teleoperator maneuvering systems, support satellites, and automation.

In summary, the Space Station operations theme will be one of low operational cost achieved by reduced ground personnel and increased productivity achieved through the enhancement of crew capability.

4.2.5 Evolutionary Attitude Control and Stabilization

This theme captures the integrated aspects of structures, dynamics, and control technology required for the initial and evolutionary Space Station. The lumped, rigid-body control systems of present spacecraft will be inadequate for the flexible, low-frequency, highly interactive dynamics of the Space Station. As the Space Station evolves, large configuration changes will add complexity by continuously modifying the structural dynamic characteristics of the entire system.

Structures and control technologies will be developed to analytically characterize the highly non-linear system and provide in-situ identification of system characteristics via on-board global sensing systems and advanced control algorithms. Technology for reconfigurable control systems will be developed to track and compensate for real-time changes and accommodate modular growth. Advanced sensors and actuators, active and passive damping techniques, and integrated structural/control analysis methods will be developed for distributed, adaptive, and modular control systems. Advanced concepts and mechanisms will be studied for inter-vehicle rendezvous and soft docking, berthing and control of modularly assembled structures, and control for precision pointing of flexible spacecraft with articulated members. Large momentum device concepts will be evaluated for integrated momentum and energy management and control of large space systems.

4.2.6 Energy Management

The advanced power system of a permanent Space Station must be reliable, maintainable, rugged, and semi-permanent, and it must have low life cycle costs. Provisions must be made for growth to higher power levels and technology advances to reduce the physical size of the power system, total system mass, and cost of delivered energy.

The power system is a dominant physical feature of the Space Station and will, therefore, be a major source of aerodynamic drag. Total system mass, using presently available technology, for a conceptual, prototypical, 25 KW, self-contained Space Station power module has been estimated to be about 16,000 kg, including the weight of the modular container. Moreover, while the cost per kilowatt has fallen significantly over the past decade, it still remains on the order of $1,000/watt for smaller, unmanned flight systems. Improvements in system efficiency and life, either through improved component performance or improved system integration, will have a major impact on the reduction of cost and power in orbit.

Power technology programs focused on these improvements include power generation/conversion via photovoltaics and fuel cells, energy storage via high-capacity batteries and fuel cell electrolysis, and power management and distribution for high-power processing, conditioning distribution, and control.

Power system technologies must be sensitive to recurring costs over the operational life of the system. Technology options that impact basic cost issues, such as autonomy, automation, maintainability, repairability, replaceability, and integration with other Space Station Systems, should be kept open as long as possible. Concurrently, detailed system analyses are needed so that accurate comparisons of expected performance and life-cycle costs can be made between the various options and combinations with other subsystems.

These analyses will enable mission planners to incorporate the technology most suitable for meeting overall program requirements.

High-power systems, for example, require technology to deal with associated large heat dissipation and, thus, require optimization of an integrated power and thermal energy management system. An integrated thermal utility, adaptable to wide variations in requirements and loads, will be required to support evolutionary growth and changes to the Space Station configuration.

Advanced technology in power production, distribution, and storage, as well as thermal acquisition transport and heat rejection, will be developed for subsystems and components to enable a high-performance, reconfigurable, integrated energy management capability in this changing environment. Technology developments will include high-voltage utility power capability, high-capacity energy storage, fuel cell electrolysis, high-performance photovoltaic arrays, bulk power transfer techniques, integrated thermal/utility bus, high-capacity heat transport, and maintainable and/or replaceable, reconfigurable radiators.

4.2.7 Integrated Hydrogen-Oxygen Systems

Consumables and their constituency and usage have a major impact on Space Station architecture. Adoption of an integrated hydrogen-oxygen system offers the potential for minimizing or even eliminating many other Space Station consumables. As major Space Station resources, hydrogen and oxygen have a wide variety of applications that include environmental control and life support systems, on-board propulsion for attitude control and station-keeping, electrical energy production and storage, thermal management, and use as propellants for high-energy upper stages via OTVs and teleoperators.

Recent studies have shown a high potential benefit associated with the economics of transportation and hydrogen-oxygen through the process of scavenging excess propellants from the Shuttle external tank (ET). Based on Shuttle revisits on a 90-day cycle, enough propellant should be available to perform Space Station altitude maintenance maneuvers. Whether these fluids are made available by scavenging the ET, manifesting payloads with tanks to maximize

Shuttle payload capability, or dedicated refueling missions, the potential exists for a more cost-effective Space Station.

Economics associated with minimizing the transportation of consumables is reflected not only in potential cost savings but also in the technology selected for power, propulsion, life support, and thermal management. Advanced technology programs directed at primary fuel cells, low-thrust propulsion systems, and management of subcritical cryogenic fluids will provide not only technology options for Space Station evolutionary growth capability, but also major system advantages.

A solid polymer electrolyte (SPE) or alkaline primary fuel cell, operating on propellant-grade hydrogen and oxygen, can produce power and store energy and provide water for crew consumption and coolant for thermal control systems. Electrical power production through fuel cells can be utilized to reduce both the Space Station solar array and battery requirements. Compounding effects result. Reduced solar array area reduces both the drag force and resultant orbit makeup propellant requirements, while reduction in battery mass further lowers the propellant requirement.

Monopropellant and bipropellant auxiliary propulsion systems meet the moderate station-keeping requirements of present spacecraft. Due to the greatly increased total energy requirements for a Space Station, substantial benefits can be achieved by raising the specific impulse (I_{sp}) of the propulsion system from the present 230-280 seconds. Conventional gaseous hydrogen/oxygen rockets and resistojets offer substantial I_{sp} increases and are complementary elements in an integrated hydrogen/oxygen system.

Projected utilization of cryogenic fluid on the Space Station has elevated the status of zero-gravity storage and transfer of cryogens to that of an enabling technology. The hydrogen and oxygen in the Shuttle, sensor instrument cooling requirements, and the potential use of the Space Station as an OTV refueling depot are only a portion of the spectrum of Space Station cryogenic interfaces. Therefore, technology for advanced insulation systems and long-life refrigeration/liquefaction systems must be developed to provide long-term cryogenic storage in space.

Space basing of OTVs introduces the requirement for large hydrogen-oxygen storage systems. The potential then exists for satisfying the majority of fluid needs of an integrated hydrogen-oxygen Space Station from those large supplies. This could be accomplished by a direct feed line or possibly by using only the normal fluid losses from the large tanks. An integrated hydrogen-oxygen system incorporated in the initial space station configuration could allow large quantities of fluid to be available for emergency power or orbit maneuvering when full Space Station potential is attained.

5.0 FOCUSED TECHNOLOGY DISCIPLINES

The Space Station technology program will be accomplished at the discipline technology level. This section defines the discipline focus for the Space Station and provides an overview of the content of the individual discipline research and technology programs. The overall Space Station technology program is contained within ten discipline areas listed below:

- Systems and operations;
- Data management;
- Crew and life support;
- Attitude control and stabilization;
- Power;
- Thermal;
- Auxiliary propulsion;
- Materials and structures;
- Communications; and
- Space human factors.

5.1 SYSTEMS AND OPERATIONS

The Space Station disciplinary systems and operations program develops those technologies that have broad multidisciplinary research applications. The *research is categorized as "systems" or "operations," depending upon the phase* of the Space Station program affected. Those research tasks needed for the basic design and development of the Space Station are labeled "systems," and those items needed to improve after-launch performed are labeled "operations."

A critical systems task is to conduct systems analysis, interaction, and sensitivity studies across the disciplines and the emerging architectural options. The system studies must also evaluate the impact of various technology options on achieving evolutionary growth (enabling or limiting). Evolutionary growth (especially technological growth) capability can be assured only through development of technology that will enable computer emulation interfaces. The fidelity of these interfaces must enable verification of system-compatible growth hardware prior to launch and integration in orbit. The challenge is to verify on the ground that a new specific element not only meets form, fit, and function requirements, but is also compatible with the total Space Station System so that unacceptable subsystem interactions are not possible in orbit. The interfaces must be capable of transmitting whatever functions are necessary independent of the technology incorporated into a subsystem. This capability of interface design has been called "technological transparency." One approach identified for achieving technological transparency is to minimize subsystem interactions through use of a high degree of hardware modularity and a correlated distributed data system. While mass penalties are certain to occur with this approach, the benefits in terms of system software and simplifying hardware interfaces may well justify the added mass.

In the operations area, the technology necessary to accomplish initial development, complete checkout, and start-up operation of the Space Station will be identified and developed. Deployment, mating procedures, and checkout of subsequent modules will be included. The long-range goal is to develop the technology required to allow standardized payload checkout and operation including the required controls and displays.

The operations area also has the broad responsibility, across the Space Station System, to assess the needs and benefits of autonomous operations. The results of this assessment will be periodically fed into other discipline technologies to guide their efforts and aid priority evaluation internal to a discipline.

Tasks will be initiated to focus on the possibility of developing generic fault detection, isolation, and correction techniques that can have broad potential applications that would simplify on-orbit operations, maintenance, and repair. As part of this effort, engineering assessment techniques will be developed to conduct trade studies of reliability (e.g., high-quality parts and extensive screening and testing), ease of maintenance, design for fault isolation, and correction to achieve lowest overall life-cycle costs.

Guidelines and standards for checkout, repair, and servicing of spacecraft on-board the Space Station and with EVA and teleoperators will be developed to identify technology gaps that must be filled. Construction, deployment, erection, and assembly operations will be studied to evaluate the degree of automation desired, the types of equipment, tools, etc., required, the technology levels necessary for advanced manipulators, teleoperators, robotics, etc., and the alignment and calibration aids required.

In all systems and operations tasks, cost and crew productivity will be important considerations. The system technology program will identify and prioritize high-leverage discipline technologies to optimize man's participation in the overall system.

5.2 DATA MANAGEMENT

The objective of the data management technology program is to maximize long-term Space Station utility by providing an adaptable high-performance system architecture that is inherently capable of being configured to serve the needs of any conceivable mix of sensors, data processors, mass storage systems, and communications services. It is recognized that the Space Station data management system will be required to adapt to changing applications and survive operationally in the event of damage or failure to any parts of the data management system, preferably without intervention by on-board crew members. A related architectural goal is to provide a common data interchange medium between subsystems whose internal technologies may differ substantially as a consequence of being created in different eras of electronic technological evolution.

The key to achieving data management system adaptability and autonomous recovery from in-orbit failures is seen in the ability to initially deploy the Space Station with massive excess capacity in terms of individual signal paths (on the order of tens of thousands) and data rates (on the order of hundreds of megabits/second) combined with switching capability at each node of an extensive on-board network. Three mutually supportive technology developments are being pursued simultaneously toward realization of this capability:

(1) electro-optical components; (2) advanced networks and protocols; and (3) modeling and analysis tools.

Present electrical conductor technology (wire, coaxial cable) will be replaced by advanced technologies that will develop guided wave optical transmission media, optical connectors, electro-optical receivers, and transmitters suitable for space flight application.

The current mil-1533 bus architecture will be superseded by development of advanced technology for network organizations, topologies, and exchange protocols optimized for use with optical transmission technology and automated system management.

New analysis tools and network models will be developed to prove the viability of candidate network architectures without relying on test bed demonstrations that are economically impractical. Additional advanced data management technology development is focused on data storage, fault tolerance, software, and expert systems.

Data storage technology to replace state-of-the-art magnetic tape recorders includes optical and/or magnetic disk technology for high-capacity and high-speed mass data storage systems, magnetic bubble memory devices, and memory subsystems for moderate-rate, non-volatile data storage.

Current redundancy management of on-line computers will be replaced by advanced fault-tolerant, self-checking computer modules for supervisory and control applications that eliminate service outages and provide the key to achieving autonomy in subsystem management.

Advanced technology in software systems will develop interface and protocol standards to improve information exchange within the Space Station and between the Space Station and external systems and reduce the cost of software implementation.

Expert systems technology will be applied to planning and control of flight operations and automation of individual subsystems.

5.3 ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Life support systems technology will involve water, air, and food systems on-board a Space Station and on EVA equipment.

5.3.1 Water Recovery

No U.S. manned mission to date has included a system to recover water and make it available for reuse by the crew. Several methods of recycling household water and water from human wastes are under development. Water condensed from the cabin atmosphere and iodinated can be used for household purposes without further treatment. Ultrafiltration and reverse osmosis are feasible schemes to extract water from solutions of low concentration such as wash water. Two low-pressure distillation techniques, vapor compression distillation (VCD) and the thermoelectric integrated membrane evaporation system (TIMES), are under development to handle higher-concentration solutions such as urine. All these methods produce concentrated brines that must be stored and returned to Earth, and none can handle fecal material. A new supercritical water system in which the water is raised above its critical point and oxygen is injected to oxidize all dissolved organic material could handle all organic solid wastes as slurries.

5.3.2 Carbon Dioxide Removal

Skylab used a molecular sieve system to absorb CO_2 from the cabin atmosphere; it was periodically desorbed by heating under vacuum. The Space Transportation System (STS) and all other U.S. manned systems have used replaceable canisters of LiOH which are regularly returned to Earth for regeneration.

Two alternative CO_2 removal systems are under development. One absorbs CO_2 on solid amine granules and periodically desorbs it by sweeping the absorbent bed with steam that drives the CO_2 ahead of it to be vented to space. The other system is an electrochemical cell, which is essentially a fuel cell with a carbonate electrolyte. In electrode reactions, CO_2 is produced along with the product water, tending to concentrate atmospheric CO_2 in the product water vapor system from which it can be extracted by condensing the water.

5.3.3 Air Revitalization

All missions up to now, including those of the STS, have replaced metabolized oxygen and atmospheric leakage from stored supplies of liquefied gas. Both oxygen and nitrogen are carried by the STS since it maintains an Earth-life sea-level atmosphere. State-of-the-art water electrolysis cells are approximately 90 percent efficient in converting electrical energy to the chemical potential energy of separated H_2 and O_2.

Cells now under development can supply oxygen with good efficiency by extracting water for electrolyzing directly from the cabin atmosphere. Thus, oxygen can be recovered directly from water vapor or CO_2, if necessary, by reduction with hydrogen on a catalyst first to obtain water. In the Bosch reaction, iron (steel wool) is used as the catalyst. In the Sabatier reaction, ruthenium deposited on alumina particles is used as a catalyst.

A method of supplying makeup nitrogen without requiring cryogenic liquid gas is also being developed. The nitrogen is stored as hydrazine and released by a multi-step catalytic process.

5.3.4 Extravehicular Activity (EVA) Systems

NASA's current EVA system uses a "soft" spacesuit that operates with a pure oxygen atmosphere at 4.2 pounds per square inch (psia) absolute pressure and a protable life support system (PLSS) that uses LiOH cartridges for carbon dioxide removal, bottled oxygen at 6,000 psia for gas makeup, and a water boiler that vents about 2 pounds of water per hour for heat rejection.

A "hard" suit is now under development that can operate within an internal pressure of 8 psia and is expected to afford improved mobility and reliability. This suit is expected to eliminate the need for pre-breathing oxygen to purge nitrogen from the wearer's body fluids before EVA operations. The most difficult problems are expected in development of a more compact PLSS that incorporates a regenerable carbon dioxide removal subsystem and provides thermal control without venting water.

5.4 POWER

Technology for advanced power systems encompasses power generation, energy storage, and power management and distribution for improved efficiency in power production, high-capacity storage, and high-voltage, high-power systems.

Power generation and conversion technology is primarily focused on photovoltaic systems (array and blanket technology) for the initial Space Station. However, more emphasis may be placed on solar thermal dynamic systems as a potential alternative to photovoltaic systems -- the long-term solution to power generation is likely to be nuclear.

State-of-the-art solar array technology is embodied in the SAFE solar array, which features 6x6 cm silicon cells mounted on a flexible, deployable substrate. The 6x6 cm cells show cost improvements over the smaller 2x2 cm SEPS solar array cells and reduce the integration and assembly costs of solar array blanket assemblies. Advanced solar cell technology for improved conversion efficiency is directed at gallium arsenide cells for high-power planar and concentrator arrays. Concentrator technology includes small area gallium arsenide cells with 20 percent conversion efficiency and blanket designs with concentration ratios of 100.

Technology for long-life blankets will be provided via advanced interconnect welding techniques that are more resistant to the low-Earth orbit (LEO) cyclic thermal environment than current solar cell interconnects. Advanced cell and concurrent reductions in costs ($/kw).

Solar thermal dynamic power conversion offers an important advantage over conventional photovoltaic systems for low-Earth orbits where drag is important. The high overall efficiency that is predicted for dynamic conversion systems coupled with thermal energy storage capabilities results in significant drag area reductions relative to photovoltaic/electrochemical systems.

A solar heated hot-gas engine is used to generate electric power. During orbital dark periods, heat is supplied from a thermal storage material. Waste heat from the cycle is rejected by a radiator. There has been no flight experience with such a system but there has been extensive ground experience on important parts of the system.

The heat engines of principal interest are the Brayton cycle turbocompressor engine and the free piston Stirling engine. Proposed work on the Brayton will adapt the 15 kw Brayton Rotating Unit, which was ground tested for 39,000 hours, to Space Station requirements. Proposed work on the Stirling engine will include development of technology and design methods for Stirling engines in the 15-30 kw range. Ground endurance testing of breadboard heat engine systems will be conducted. Components such as mirror, receivers, heat storage materials, radiators, and coatings will be designed and tested for endurance, durability, Shuttle storage, and development/erection techniques. Throughout the proposed program, flight tests will be conducted as appropriate to confirm designs, component and subsystem behavior, and durability and performance of prototype systems.

Energy storage technology includes high-energy-density Ni/H_2 batteries and regenerative hydrogen/oxygen fuel cells. Present satellite energy storage is accomplished with NiCd batteries with 8 Wh/kg capacity at 28 Vdc.

The Ni/H_2 battery offers at least a 2 to 1 advantage with a potential 5 to 1 advantage in energy density compared with present NiCds. Advanced technology to develop large-area cells, improve battery packaging, and increase depth of discharge is expected to produce a high-voltage, long-life, high-capacity bipolar Ni/H_2 battery with improved reliability and insensitivity to overcharge/discharge.

Fuel cell/electrolyzer storage systems have a per-orbit energy density equivalent to the NiH_2 battery and lead bipolar Ni/H_2 battery development. Advanced hydrogen/oxygen regenerative fuel cell technology is being developed for both solid polymer electrolyte and alkaline electrolyzers for breadboard integrated system testing in the range of 6 to 7.5 kw.

Ultimate LEO power capability of hundreds of kilowatts with at least 40,000/hour lifetime is expected.

Power management and distribution technology includes high-voltage, high-power components for processing, conditioning, and transmission, power system breadboards, and associated automation and environmental interactions.

Component technology is directed at high-power systems of 100 kw and beyond for AC and DC applications. Breadboards will be utilized to develop models, sensors, and algorithms for autonomously-managed power systems. Environmental interactions technology is investigating the LEO plasma environment, generating analytical models of high-voltage space plasma interactions, and developing techniques to minimize charging, arc discharge, and plasma drain.

5.5 THERMAL

Thermal management is the judicious dissipation and/or use of the available thermal energy to properly condition a spacecraft in an efficient, simple, reliable, cost-effective manner.

Thermal management has not been an overriding driver in previous spacecraft designs. Relatively short missions and total system lifetimes did not require long-life considerations or extremely high overall system efficiencies. Conventional heat rejection systems require a significant degree of vehicle integration. To achieve system reliability for long-duration missions, Shuttle-type systems would be heavy and complex due to redundant pumping, plumbing, and valving hardware.

For the next generation of space missions, particularly manned Space Stations, longer lifetimes and higher power levels will be required than in any previous missions. Thermal management is mandatory because generation, transfer, and storage of the electrical energy needed for Space Stations will result in the dissipation of huge quantities of waste heat. A low-cost, reliable, thermal management system does not currently exist and must be provided to support Space Stations. Such a system would need to overcome the limitations of current system designs, thus requiring an entirely new effort in thermal management.

The three primary goals that must be achieved to support a Space Station program in the area of thermal management are: (1) Long-life heat rejection; (2) versatile thermal acquisition and transport; and (3) efficient thermal utility system integration.

Heat rejection focuses on the technologies addressing the final transfer of waste heat from the spacecraft to the ambient environment by radiation. Space Station heat rejection applications require reducing weight and complexity and increasing reliability. The technology also requires advancement in order to achieve the manufacturability and heat rejection demands of large, centralized thermal management systems.

Thermal acquisition and transport focus on technologies that address the collection and movement of thermal energy from heat sources to heat sinks. It is believed that the key to Space Station thermal acquisition and transport lies in the creation of a thermal "utility" or bus system analogous to municipal public utilities, where basic "trunk" lines are provided and into which individual customers can be integrated. The system must be designed so that changes in location or load of individual customers have minimal effect on the utility's capability to serve the remaining customer's loads. This goal will probably eventually lead to a two-phase, near-constant temperature heat sink.

System integration focuses on technologies that address the cumulative performance of elements within a thermal management system and the system's interaction with other spacecraft systems. For Space Stations, integration of heat sources and heat sinks into a thermal management system will become necessary so that a variety of temperature levels and degrees of control can be provided automatically and efficiently to multidiscipline users. On-orbit maintainability and serviceability complemented by periodic refurbishment operations must also become a reality if realistic operational life and costs are to be achieved.

Such a centralized system would allow reduced operational and payload integration costs and reduce costs for all payload users by allowing common thermal designs.

5.6 HUMAN PRODUCTIVITY

Given our operational Shuttle, the next logical step in America's space program is a more permanent presence of man in space. This will initially take the form of a manned Space Station. NASA has recently instituted a human factors research program to ensure the timely availability of man-machine interface design technology for the space program.

Past experience, as well as automation technology forecasts, point to a need for the human's unique capabilities in a maximally effective and efficient program to utilize and exploit the potential of space. However, the high cost of each man-hour in space, the difficulty in handling injuries, and the adverse public sentiment that would result from mission failures require that humans in space be provided with maximally effective and safe tools, procedures, and work stations.

The goal of the space human factors program is to develop the technology for: (1) Determining which tasks should be done by humans and which by automation; (2) determining which human tasks should be done in the shirtsleeve environment of the spacecraft and which in the EVA environment wearing spacesuits; and (3) developing methods for designing safe, effective tools, procedures, and crew stations for astronaut use. The program to accomplish this is divided into the following five elements:

(1) Basic methodology;

(2) Crew station design;

(3) Ground control/operation;

(4) Teleoperations; and

(5) Extravehicular activity.

Basic methodology encompasses the development of human factors techniques, methods, data bases, and standards to design and evaluate human/system interfaces for use in space anthropometry, methods for formating support documentation, and methods for allocating tasks to humans and to automation.

Crew station design focuses on developing methods and techniques for using advanced display and control technology (e.g., flat panel displays, touch-sensitive panels, voice recognition/synthesis, etc.) in more efficient crew station design.

Ground control operation encompasses the development of techniques for designing ground control stations requiring few human controllers and solving the human implications of transferring operations (e.g., assembly, test, and launch) from the ground to a Space Station.

Teleoperations focuses on the development of man/machine interface requirements of teleoperators (remote manipulation devices). This includes visual and tactile feedback to the human, as well as information input methods.

Extravehicular activity encompasses the development of improved tools, procedures, and work stations for the suited astronauts and the design of equipment for ease of servicing by extravehicular activity.

5.7 AUXILIARY PROPULSION

Auxiliary propulsion has several key technologies that are required or could potentially benefit the Space Station in the areas of auxiliary propulsion and fluid management systems.

5.7.1 Auxiliary Propulsion System

The auxiliary propulsion system will provide attitude control, orbit maintenance, acceleration control, and de-orbit control of the Space Station. The conventional Earth-storable monopropellant and bipropellant systems can be readily used and are sufficiently developed so that they do not require any technology advancement. Other propulsion concepts that may be beneficial to the Space Station and need technology advancement are described below.

5.7.1.1 Thermally Augmented Propulsion System

The thermally augmented propulsion system employs thrusters wherein the working fluid is heated by an external source before its expulsion through the thruster nozzle. Waste heat or electrical energy at low power level can be used to condition a cryogenic fluid such as hydrogen to a temperature of 70°F at which state it can deliver a specific impulse of 325 seconds. Higher temperatures using best storage heat exchangers and low power continuous electrical heaters can be produced. At 1,600°F, hydrogen can deliver a specific impulse of 600 seconds.

5.7.1.2 Gaseous Hydrogen Oxygen Auxiliary Propulsion System

This system utilizes a propellant conditioning system to periodically pump, vaporize, and store hydrogen gas and oxygen gas for subsequent feed to the individual thrusters. This system could potentially greatly reduce Space Station operating propellant and resupply requirements, reduce life cycle cost, increase system life, reduce contamination, and reduce operational complexity (i.e., non-toxic scavenging and life support systems).

5.7.1.3 Resistojet System

Resistojets are low thrust, monopropellant thrusters that can use a variety of gaseous propellants (N_2, H_2, CO_2, NH_3, CH_4, etc.) but also require relatively large amounts of instantaneous electrical energy. Such a system would only be viable on a vehicle with large quantities of cheap electrical power. The resistojet system, because of its inherent low thrust levels, can be most propitiously used for sustained acceleration control.

5.7.1.4 Electrothermal Propulsion Research

Advanced resistojets and solar thermal rockets offer very large improvements relative to today's propulsion concepts over an extremely broad operating envelope. Specific impulse up to three times that of a chemical system might be possible with some concepts at thrust levels on an order of magnitude greater than possible with present electrical propulsion.

5.7.1.5 Inert Gas Ion Propulsion System

Infer gas ion thrusters offer the highest performance of the candidate advanced propulsion concepts. High specific impulse propulsion systems with low propellant requirements may be advantageous in reducing the total propulsion resupply requirement. Higher performance may also translate into longer life and lower system maintenance requirements.

5.7.1.6 Propulsion System Diagnostics

A basic requirement of the Space Station is an on-orbit monitoring capability of the propulsion system health so that timely corrective action may be implemented prior to any actual failure. Means for monitoring component performance, fluid leakage, electrode deterioration, and chamber burnthrough should be developed.

5.7.2 Fluid Management Systems

The functions of the fluid management systems would include orbit transfer vehicle propellant resupply, satellite fluid resupply, experiment fluid supply, and Space Station subsystem fluid supply (e.g., auxiliary propulsion, energy, life support, purge, and thermal control).

High-leverage fluid management technologies that will be pursued for the Space Station include: (1) Leakproof fluid coupling and lead detection techniques to enable safe and contamination-free fluid transfer; (2) zero-gravity fluid quantity gauging devices; (3) reusable insulation systems for the Shuttle tankage which will be used to transport cryogens to the Space Station; and (4) long-term orbital cryogenic liquid storage facilities possibly employing refrigeration and/or liquefaction systems.

Auxiliary propulsion trade studies will also be conducted in the fluid management area to establish: (1) The desired crossover point from subcritical to supercritical cryogen storage and modular replacement to tanks vs. fluid resupply in terms of fluid quantity, system weight, operational simplicity, and Earth-to-orbit transportation costs; and (2) the desired degree of centralization/integration of fluid storage and supply subsystems including consideration of the use of common fluids that can adequately meet the requirements of several Space Station subsystems rather than choosing an optimum fluid to meet each Space Station subsystem requirement.

Since LH_2 and LO_2 will be required in large quantities for fueling space-based OTVs and are likely to be required by some Space Station subsystems, a related trade study should be undertaken to establish the preferred approach for transporting these fluids to the Space Station. Methods of scavenging propellants from the Shuttle orbiter and external tank should be evaluated to define required Shuttle modifications, performance penalties, and quantities of recoverable fluid available.

The most attractive propellant scavenging technique can then be compared on an economic basis to: (1) Dedicated Shuttle resupply flights; (2) manifesting payloads for maximum utilization of Shuttle capability by transporting fluid tanks of different size, weight, and geometry; and (3) Earth-to-orbit transportation of water followed by the on-orbit manufacture (and liquefaction) of propellants.

5.8 ATTITUDE CONTROL AND STABILIZATION

The control technology goal is to develop and validate the technology base required to enable Space Station missions in the 1990s. Advanced control technology is a key factor for ensuring the success of a Space Station mission because advanced control technology can provide system designs that offer better performance, higher reliability, lower cost, and lower risk than with current design technology. In addition, advanced technology will be pivotal in developing automated systems that require fewer ground support operations and allow the crew to carry out higher level functions.

The challenges in developing Space Station control system designs arise in three principal areas: (1) Automated systems management of a highly complex, man/machine system; (2) precision pointing control and stabilization for a non-rigid structure that has an evolving in-orbit configuration; and (3) modular systems that have high reliability and long life. To meet these needs the Space Station control system must be adaptable, adaptive, modular, robust, multifunctional, fault tolerant, and highly autonomous. In order to design and build such a control system, several key control technology areas must be developed. These area include adaptive control, autonomous control, goal-oriented hierarchical control, autonomous real-time system identification, vibration control, shape control, distributed control, intelligent man/machine interfaces, teleoperator and robotic control, plus long-life, high-reliability hardware.

These concepts have been used to formulate the advanced control technology development program, which is organized into five major areas: (1) Control system synthesis; (2) control analysis technology; (3) guidance and control components; (4) flight software technology; and (5) control test and evaluation.

Control system synthesis tasks will establish control requirements, develop control system design and mechanization concepts, and determine the associated cost and risk for the Space Station System consisting of the manned Space Station, the Teleoperator Maneuvering System (TMS), and co-orbiting unmanned science platforms.

Control analysis technology tasks focus on developing fundamental concepts and techniques in the areas of modular control, system identification, adaptive control, distributed control, non-interactive control, teleoperator and robotics control, autonomous navigation, precision platform or payload pointing, and technology integration.

Guidance and control component tasks will concentrate on developing advanced guidance and control sensors and actuators and related instrumentation for docking and rendezvous, shape and vibration control, precision actuation, and pointing of large space systems.

Flight software technology tasks are aimed at developing highly reliable control systems that function autonomously and adaptively. These tasks will develop control software that will operate in a multiobjective fashion to provide goal-oriented performance.

Software packages will be of a modular, fault-tolerant design that can provide high reliability and low risk. They will also be combined into a larger package to develop a highly autonomous system capable of self-monitoring and management.

Control test and evaluation tasks will address the problems of validating GN&C hardware/software technology readiness. Methods and procedures will be developed and used to design, integrate, and evaluate the performance of complete GN&C systems as well as individual hardware, software, or emulator components.

5.9 STRUCTURES AND MECHANISMS

The materials and structures program, established to provide technology readiness for Space Station requirements, consists of three major areas: (1) Space-durable materials; (2) advanced space structures; and (3) analysis and synthesis. The program is structured to provide some near-term results to support an initial Space Station configuration. It also establishes the technology baseline to allow evolutionary growth in a Space Station structural concept from a single module to a complex, multifunctional configuration. Each major area in the structures technology program is discussed below.

Three principal elements in the thrust to establish the long-life durability of materials are dimensional stability of composites, thermal control coatings, and space debris impact.

Space platforms in Earth orbit will be subjected to many thermal cycles. It is known that thermal cycling causes microcracking and/or microyielding in both resin-matrix and metal-matrix composites which in turn, changes their dimensions and thermomechanical properties.

Current data also indicate that mass loss due to outgassing causes dimensional changes. An accumulation of small dimensional changes in the elements of large truss-type structures envisioned for space platforms could result in warping and misalignment of various components of the platform. This activity will conduct research on thermal expansion behavior of composite laminates and structural subelements. It will also develop analytical models to predict dimensional changes during space service life. This will provide needed information for designers to efficiently utilize and evaluate composites as structural materials for a Space Station configuration.

Existing paint-type, thermal control coatings add considerable mass to spacecraft and are known to degrade with time in the space environment. Degradation has been attributed to both long-term radiation effects and surface contamination. The goal of long life for a space platform will require stable, long-life thermal control coatings with tailored solar absorbance, emittance, and electrical conductivity. In the event that coating deterioration cannot be prevented or damage is incurred, then simple methods of repair must be devised to restore coating qualities. Research will be carried out on both metallic and oxide vacuum-deposited and pigmented coatings. The solar absorbance to thermal emittance ratio and electrical conductivity will be tailored for operation over a -50°C to 100°C temperature range and provide improved resistance to spacecraft charging. These coatings will be exposed to electron, protron, and ultraviolet radiation under actual and simulated space flight conditions and evaluated for long-term space durability. Contamination effects from STS operations will also be evaluated. Near-term work to support space platform needs will focus on integral coatings for composites and durable/repairable coatings.

Composite materials used in space structures will be exposed to both meteroid and manmade debris particles traveling at velocities of 20 km/sec. and 10 km/sec., respectively. The reduction in composite properties due to hypervelocity impact with space debris has not been investigated as has already been done for aluminum alloys. No data are available to assess the debris impact threat to large space systems or to evolve designs that minimize this threat. Likewise, there has not been an evaluation of these materials for possible fragmentation and debris generation. Metallic and non-metallic composite materials will be subjected to hypervelocity testing representative of the dynamic impacts encountered by spacecraft collisions with natural and man-made particles in near-Earth orbit.

These materials will initially be evaluated as single thin sheets 1 mm to 10 mm thick for survivability debris size distribution and for thickness required to prevent penetration, relative to impact energy or some other dynamic property. The tests will be repeated in a double sheet or bumper configuration to determine penetration resistance relative to the single sheet shielding. Finally, small spherical tanks pressurized with water or alcohol and filament wrapped and cured to form a shell will be tested to determine the thickness required to survive and the size distribution of fragments created when penetrated. The results obtained will be compared with data available for aluminum. The space debris testing and subsequent evaluation will be completed by 1985. This will provide a data base for the evaluation and application of composites in the Space Station design evolution.

Two principal, focused activities of the advanced space structures program are development of advanced structural concepts and mechanisms research. The Space Station design will be an evolutionary configuration and will result in unique problems in structural design. To obtain low transportation costs to orbit, the Space Station structural components must be packaged efficiently in high-density modules with minimum Shuttle volume fraction. Once in orbit, Space Station structural elements must be deployed, erected, and assembled with a high degree of reliability. The primary design considerations for advanced erectable and deployable structural concepts are lightweight structural members, compact and efficient packaging, and structurally predictable and reliable deployment. Deployable and erectable structures (e.g., beams, platforms, volumes) offer many advantages for construction of major Space Station elements and structural components ranging in size from five to several hundred meters. Structural design studies will be conducted, test hardware fabricated, and selected structural concepts tested to demonstrate technology readiness by 1986. A design guide for application to future Space Station configuration will be developed and will include structural concept descriptions, required interfaces, weight parameters, versatility, stowage/deployment volume ratio, cost data, and assessment of reliability.

Mechanism technology requirements include the capability to conduct integrated, three-dimensional, structural/kinematic analysis, develop mechanical elements (latches, connectors, and umbilicals) and programmable controlled mechanical devices, and develop soft docking/berthing systems. Advances in mechanism technology must be achieved to ensure long-life reliability in the space environment and avoid costly design problems. Development of mechanical systems kinematic analysis capability, including elastic effects, tolerances, and interference, will permit complex mechanism simulators and subsequent improved design quality. "Smart" mechanisms will be developed utilizing microprocessors that would allow sensor feedback and multifunctional performance capability. A further need in the mechanisms area is the development of reliable moving joints, seals, and latches that have minimum deadhand, low coefficient of expansion, long life, and high functional reliability. One significant mechanism system development for a Space Station is an advanced docking capability. Concepts will be developed to substantially reduce docking loads (velocities less than 0.1 ft./sec.) and provide payload berthing capabilities. An integrated mechanism research program will be initiated beginning in Fiscal Year 1984.

Two principal elements underlying the analytical capability required to support the design and development of Space Station structural configurations are system identification and dynamic response, and integrated analysis and optimization methods. Due to limitations on Earth-based testing (e.g., gravity effects, size limitations, and air damping), analytical predictions of the dynamic behavior of Space Stations will be more heavily relied upon than they are for conventional aerospace vehicles. Accurate, efficient, and reliable methods for non-linear transient and steady-state dynamic responses of interconnected multibody Space Station configurations are required. These configurations may consist of pressurized shells, flexible booms, membranes, and other appendages. Methods must consider the interactive dynamics of these components with a control system under external excitation arising from slewing, docking, rotating and moving machinery, crew motion, drag, and propulsion loads. Space Station configurations and structural components will likely have very low frequencies with low inherent damping. To prevent excessive structural response due to external loads and control forces, reliable techniques must be developed for introducing active/passive damping into these structures without adversely affecting performance or integrity. Many current structural identification methods work well in idealized computer exercises but fail in actual applications using test data. New methods will be developed addressing such issues as required ground test methods, optimum sensor location, effect of noise on the measurements, time domain versus frequency domain methods, and identifying closely-spaced modes. The methods developed will be applied to a realistic benchmark problem to evaluate their validity and relative merits for utilization in on-orbit system identification. Also to be investigated are the types of sensors required for system identification methods.

The objective of integrated analysis and optimization technology is to develop efficient and reliable multidisciplinary and optimization methodology to support analysis and synthesis of Space Station structures, including thermal and controls analysis. Using this approach, the entire Space Station configuration and associated technical disciplines are considered as an integrated system, and various design tradeoff evaluations can be conducted. An archival engineering data base system is required to support this activity. The data base would be accessible to from various working data bases that could be altered at the analysts' convenience. This capability would facilitate information transfer and tracking between NASA Centers and contractors. The research goal is to develop an integrated structures/thermal/controls analysis and optimization capability by FY 86.

5.10 COMMUNICATIONS

The objective is to develop communications technology options for a permanently manned, evolutionary Space Station. This technology will cover telecommunications and metric tracking requirements for housekeeping, teleoperations and vehicle services, traffic control, captive payload services, and cluster telecon services. Voice conferences can currently accommodate 4; the objective is to extend the capability to 20. Current Ka-band radar can only track one object at a time. The need exists to track 2-3 objects by 1990, 5 by 1995, and 20 by the year 2000. Presently, Ka-band radar can track down to 30 meters; the goal is to track down to contact. Currently, EVA activities can only handle 2. The desire is to extend the capability to 3-5 by 1994. The present uplink capability is limited to 299Kb/s; 18-22 Mb/s is required to provide live TV uplink. Current downlinks are limited to 50 Mb/s. This capability must be extended to 300-500 Mb/s. The cost of phased arrays for spherical coverage and multiple tracking can be reduced by a factor of 2. To gain 10 dB jamming protection against expected RFI background increase, the signal must be spread by a factor of 10 in bandwidth because fixed bandwidths will result in a loss in bit rate by a factor of 10. The capability of operating the expected 10 different types of optical and RF external links, numbering in quantity from 16 to 31 with a minimum of 10 links operating simultaneously, must be assured.

The general approach is to establish the communications requirements for the Space Station, perform analytical analyses and trade studies to support selection of alternatives, identify critical technology items, perform conceptual designs, and implement the designs in breadboard systems.

The communications technology program is focused on spherical coverage and associated vicinity operations, traffic control, multiple access communications, and multifrequency, pointing, tracking, and scanning technology for high-gain antennas.

Studies will be conducted to identify the most appropriate and critical technologies required to provide spherical coverage of communications and tracking functions for the Space Station. In conjunction with scale model testing, predictive analytical codes will be developed and validated.

A multiple access technology base will be established for advanced space platform applications. Advanced components will be developed and evaluated in integrated breadboard tests.

Advanced laser technology will be utilized to support traffic control and vicinity operations and will include development of advanced concepts and components for precision close-range tracking of multiple targets with controlled closure to final contact for docking and berthing.

Antenna technology will be directed at advanced concepts, component development, and breadboard test and evaluation. Limited electronic scan high-gain and laser antenna feed techniques will be developed for electronically acquiring and tracking out mechanical jitter in high-gain pointing systems. The technology base will be established for Ka- and Ku-band monolithic microwave integrated circuits for phased array cost reduction and for multifrequency high-gain antennas.

6.0 PROTOTYPE TECHNOLOGY

(TBD)

7.0 TEST BEDS

The Advanced Development Program will serve to bridge the gap between technology advancement and its use in the development phase (DDT&E) of the Space Station program. Integrated system test beds, in key technical disciplines, are seen as a vital transition mechanism in this process. Inasmuch as the Space Station will have subsytems, such as electric power, life support, and thermal, that will be more complex than those of previous space programs, the need exists for a comprehensive method of demonstrating the viability of new technologies. The integrated subsystem test bed approach to system-level verification provides an effective means for accomplishing this.

This section will describe the test bed program, in selected key technical disciplines, which is designed to demonstrate technology feasibility and maturity for Space Station application.

Desired test bed end-items will be documented in formal plans through inter-center participation. They will include, but not be restricted to: (a) Periodic review of objectives and test procedures, and based on results of the reviews, redirection if required; (b) test reports and review comments; (c) anomoly investigation reports to include results of efforts by technology/ hardware developers and/or suppliers; (d) outside investigations for special problems; and (e) final reports with recommendations for system implementation.

7.1 DATA MANAGEMENT SYSTEM TEST BED

The Space Station Data Management System as presently conceived will be an assembly of distributed data networks with such attributes as modular design for orderly long-term evolution of system capabilities; standard interfaces and common hardware and software for decreased life cycle costs; "user friendliness" for ease of operation by users with a minimum of special education and training; and fault tolerance to achieve levels of reliability and safety necessary for routine orbital flight operations. It includes within its scope not only data system networks on board the Space Station, but also ground networks and associated communication networks required for Space Station operation as a manned orbital facility and as a platform for scientific experiments and payloads.

The Data Management System (DMS) test bed will represent a step beyond the classical evaluation and demonstration of point designs. It will serve as a proof-of-concept prototype for advanced technology and for formulation of a systems engineering methodology to deal with distributed data systems architecture. This will require that the DMS test bed support not only carefully structured testing for critical elements and/or design concepts, but that its activities also be coordinated with, and in some instances, tested against interfacing subsystems and user requirements. The point of these tests will be both to develop and verify interface specifications and to formulate guidelines and technologies for establishing and insuring compatability of user requirements with DMS capabilities.

The DMS test bed program will be a complimentary multicenter effort to make use of significant physical facilities and technical expertise at each center. The centers involved include ARC (analysis and simulation); GSFC (end-to-end design); JPL (autonomy and automation); KSC (system checkout); LaRC (technology development); MSFC (system integration); NSTL (user requirements); and JSC (space station core data system and overall test bed management). A brief summary of the individual roles of each center is as follows:

AMES RESEARCH CENTER (ARC): The majority of distributed systems are generally traditional (vonNeumann) designs with network software added to allow intercommunication with other computers. The purpose of the ARC test bed will be to insure that the data system architecture proposed for the Space Station can be upgraded, both in hardware and software, to take advantage of new technologies such as non-vonNewmann architectures and optical computers in a cost effective manner with minimum impact on existing software, network communications, subsystem wiring, and system hardware architectures. The degree to which dependence on physical factors such as information exchange, fault tolerance, software protocols, etc., can be hidden from the user, i.e., made transparent, will also be included in the investigation.

GODDARD SPACE FLIGHT CENTER (GSFC): The multi-discipline nature and increased complexity of payload deployment and user interation with the Space Station requires thorough end-to-end testing to identify procedures and technologies that will provide the necessary system operability, reconfigurability, data acquisition control, data processing and data management support. GSFC envisions a Space Station user information system that consists of the onboard user data system, the communication links to and from payload control centers, and the delivery of information to the user whether by broadcast satellite, microwave or hardware. The objective of the GSFC test bed will be to provide a reconfigurable and functionally evolving facility for user systems where various data system architectures involving distributed processors, data bases, mass storage, and ancillary data devices may be integrated and evaluated. Initial results will establish feasibility of and provide specifications (Phase C/D) for a cost effective user system that incorporates modern, high pay-off technology. In later phases, the GSFC test bed will serve as a user operational test bed and will support evolutionary advanced technology evaluations.

JET PROPULSION LABORATORY (JPL): The JPL Autonomous Systems Facility (ASF) will support the DMS test bed in the areas of autonomous operations and autonomous maintenance. The ASF will be capable of operating independently or as an integrated subsystem of the main test bed facility at JSC. When the ASF first becomes operational, the facility will permit early evaluations of the impact of automation on the selected DMS architecture. It will also be used to evaluate other proposed architectures, candidate subsystem approaches, and crew/machine and ground/machine interfaces. It will allow performance verification of autonomous hardware and software supplied by other centers or contractors.

JOHNSON SPACE CENTER (JSC): This test bed, as proposed by JSC, will concentrate on critical hardware and software issues associated with development of the data management system required for integration of the essential flight systems necessary for Space Station operations. As dictated by development schedules and program resources, the initial core FDS implementation will be based on a limited set of technology options. However, it will be fundamentally important to achieve a design concept which is receptive to new technologies and compatible with evolving requirements over the total program life. Development and demonstration of those precise attributes will be a primary objective of the proposed test bed. Close cooperation and interaction with the various other constituent DMS test beds will be essential to realization of that objective.

KENNEDY SPACE CENTER (KSC): The major functions of the KSC test bed will be twofold: to develop and test advanced, automated real-time monitor and control systems required to process and checkout the various Space Station modules and associated ground support equipment at KSC and other related areas; and to evaluate High Order Languages (HOL) for user friendly interfacing as well as preprogrammed sequences required for the monitor and control on on-board subsystems and the subsystems-related ground support equipment.

LANGLEY RESEARCH CENTER (LaRC): LaRC will not have a specific test bed facility as such, but instead will support the DMS test bed program through the development of advanced technology for both the initial and growth Space Station configurations. This will include advanced information networks; high capacity data transmission; high speed processors; software languages and tools; and solid state memories. As appropriate, LaRC will furnish prototype hardware and software to other participating centers for evaluations in their test facilities.

MARSHALL SPACE FLIGHT CENTER (MSFC): The activities to be conducted at MSFC as part of the overall DMS test bed program are planned to compliment and support tasks at JSC, GSFC, and other participating centers. The MSFC test bed will address both the core data system provided for basic management and operation of the Space Station as a facility and the end-to-end requirement for management of user science and applications data. The MSFC test bed areas of activity include the study of interactions with subsystem test beds; the evaluation of new technology; the design of local bus network configurations; the evaluation of processor and software methodologies for application to distributed systems; and user science data system interactions.

NATIONAL SPACE TECHNOLOGY LABORATORY (NSTL): NSTL will establish an advanced development test bed to evaluate data processing concepts that have been identified as Space Station requirements including: multiprocessors to distribute the data processing work load; software upgrade "on the fly" in a manner that does not impact previously implemented software or ongoing operations; the problems associated with the mixture of payload data with sensor data in the same data system, and techniques that minimize problems experienced in past space missions; and techniques for safeguarding or securing data files that are sensitive or classified, and the safety of these techniques from compromise.

7.2 ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEM TEST BED

In order to support a Space Station Phase C/D effort, readiness of the Environmental Control and Life Support Systems technology must be demonstrated. The multifaceted Regenerative Life Support Test Bed Project will (1) Evaluate integrated manned system level performance under representative conditions with a "Technology Demonstrator" prototype class of hardware developed specifically for Space Station application; (2) provide continuing design and test support for developing alternative concepts for capability enhancements and growth options; (3) conduct long-term evaluation of critical components; and (4) assure compatibility with other Space Station technology elements.

Since the mid-1960's, efforts within the NASA have been underway toward assessing regenerative life support technology readiness, primarily on a subsystem basis. Where life support technology was already in its initial development for other applications similar to manned spaceflight, e.g. for nuclear powered submarines, the technology was adopted and modified as required to make it more compatible with space-based operation. In order to assess the maturity of the various subsystem technologies for eventual Space Station application, NASA initiated in late 1969 an early unmanned test bed program for evaluation of 6-man capacity subsystem hardware. In order to accomplish this test program, a separate facility was designed and built at JSC specifically for testing regenerative life support hardware. This early version of a test bed contained all of the power, thermal, fluid supply and physical interfaces which would be provided onboard a Space Station. From the test program conducted in this facility, subsystem process efficiencies were determined, subsystem production rates were established, and parametric characterizations of each subsystem were obtained. Also, subsystem technologies which lacked sufficient maturity and candidate alternative concepts were identified. Integrated system level testing at this phase was limited to verifying compatibilities at subsystem to subsystem interfaces.

In the mid-1970's, this early regenerative life support development test bed was upgraded and modified to support "pre-development" technology assessment during the Regenerative Life Support Evaluation (RLSE) Program. Intended to support an eventual flight demonstration of regenerative life support hardware onboard the Spacelab, the RLSE Program produced subsystems sized for 3 men which incorporating the design improvements identified during the previous test program and subsystems based on alternative concepts. Subsystem level testing and evaluation have been continuing since 1978 and will conclude in 1984 with an unmanned integrated test of both the Air Revitalization and Water Recovery Subsystems groups.

The need for additional development in this technology class has been established. Primarily, the assessment of the technology readiness of alternative processes must be expanded to include alternative urine water recovery, CO_2 removal, and CO_2 reduction techniques in order to be able to satisfy the evolving program requirements for the Space Station (e.g., no dump requirements). Additionally, the exploration of process enhancements in selected areas is required in order to achieve the necessary efficiency and reliability.

Objectives of the ECLSS test bed project will be directed toward demonstrating the maturity of both subsystem as well as system level technologies. Integral with the test bed program, the design, fabrication and testing of a Technology Demonstrator offers the following program benefits:

- It will accomplish the "man-rating" of an integrated regenerative system. To date, the preponderence of experience has been accumulated through unmanned subsystem-level testing. Some relevant manned integrated system testing using regenerative life support techniques has been conducted, the most recent of which was the 3-man/90-day test conducted in 1970.

- The Technology Demonstrator will be essential in the operational assessment of a regenerative life support system. Yet unresolved are many key issues including detailed assessment of total system dynamic performance, response to subsystem and vehicle-initiated transients, and the effects on continuous life support system operation under varied power levels during an orbital period. Other issues to be addressed will include conducting detailed mass and thermal balances, quantifying the effect of man on the operation of the life support system and assessing the effect of the environment control system on the crew (e.g., noise, crew time required for maintenance, etc.).

- It will be instrumental in the assessment of inflight maintenance approaches and implementation techniques. Due to the long on-orbit life requirements, the life support system must be able to tolerate component failures while maintaining critical life support functions. The Technology Demonstrator must develop and apply the mechanisms for automating the fault detection and isolation process and demonstrate through rigorous test and evaluation that the inflight maintenance and automated redundancy management capability achieves the required degree of system reliability.

- The Technology Demonstrator will permit an assessment of future development risk associated with various subsystem approaches. It will facilitate the efficient resolution of problems encountered during the Design, Development, Test and Evaluation (DDT&E) phase of the Space Station program and indicate where additional effort and resources may be required. The inhouse test capability will enhance the NASA's ability to provide appropriate and timely guidance and assistance to the prime contractor, and to offer program options for updating test hardware to flight configuration. Segments of certification testing and solutions to flight problems encountered early in the operational phase could be realistically and more fully evaluated in the proposed test bed. Finally, it will serve as the demonstration article for evaluating both the alternative technologies as they develop and the growth options and capability enhancements as they evolve throughout the Space Station program.

7.3 POWER SYSTEM TEST BED

7.3.1 Test Bed Activities

The present-day set of baseline technologies for a Space Station design would have to consist of a silicon cell low-voltage planar array; NiCd battery system; and a 28-V DC nonautomated distribution system. None of these less desirable zero-risk fallback options are recommended, however, because the use of one or a combination of these technologies would result in a non-optimized system. However, it is anticipated that the advanced development program will, by 1987, bring some technologies to the ready level for initial Space Station consideration and some to the near-ready level for growth Space Station consideration. Candidate technologies include RFC energy storage, NiH_2 bipolar batteries, inertial energy storage, (possibly integrated with attitude control system), high voltage DC and high frequency AC distribution, autonomous power management, and high voltage concentrator solar arrays. The system/test bed nature of testing requirements for these technologies warrant their inclusion in the advanced development program.

The approach to technology development for Space Station application is a multiple one.

- Establish an electrical power system test bed using ready technologies for power generation and energy storage and begin testing to investigate power management and distribution methods and components for both AC-DC high-voltage systems and to define requirements. The system test bed would be supported by necessary subsystem test beds and component breadboards in such areas as RFC, inertial energy storage, bipolar batteries, and power switchgear and components.

- Push the near-ready technologies to maturity for the FY 1987 decision date.

- Promote the advancement of the promising, but less mature growth technologies for use either as alternatives to the ready technologies in the event of unforeseen development problems or for use on a second-generation Space Station.

- Incorporate near-ready and/or growth technologies into power system test beds at the earliest possible time for the purpose of evaluation, systems integration verification, and requirements definition revision. At any time, test beds will focus on the highest available technology consistent with program risk/cost.

Effort is required in the advanced development program to move candidate technologies sufficiently ahead for a Phase C/D contractor to begin system development work as described in the following sections.

7.3.2 Power Generation

The primary focus of the advanced development program is to develop the GaAs cell concentrator array. This type array is attractive for several reasons.

First, the concentrator array is approximately 25 percent smaller in area per watt than planar arrays. Second, previous studies of multi-hundred kilowatt arrays conducted for OAST have established that concentrator array systems with concentration ratios (CR's) to 100 have a potential for significant initial cost reduction compared to planar arrays while being capable of generating high ultimate power levels.

The evaluation of interactions between the Space Station and its orbital environment on systems operations (i.e., plasma and contamination) is essential to ensure an operationally successful design. For Space Station orbits, the interactions of a high-voltage (greater than 100 volts) solar array with the plasma environment and resulting potentials between the Space Station and the space plasma are of primary interest. Resolution of this question is the primary objective of the VOLT series of flight experiments which in effect serve as the principal test bed for solar arrays.

Large-area solar arrays and concentrator arrays are expected to require a robust structure for support and/or deployment. Further development of a concept for the much larger and more massive arrays for low Earth orbit (LEO) Space Stations may be required.

An alternative to the large area and consequently greater drag and resulting higher reboost requirement associated with photovoltaic arrays is the dynamic conversion system. Systems such as the Brayton, Rankine, and Stirling could reduce area requirements by up to 75 percent, since the charge/discharge efficiency of the dynamic system is approximately four times that of the best photovoltaic/battery system. Additionally, they are possibly more state-of-the-art than the concentrator GaAs array. These alternative options will be evaluated in the advanced development program.

7.3.3 Energy Storage

The fuel cell has been used for primary power on the Shuttle and an electrolyzer was designed, but not flown for life support capability. The RFC energy storage system represents a near-term advanced development program of integrating the fuel cell and electrolyzer with an energy storage system and demonstrating a 5-year life. This system has several advantages over a battery system, such as lighter weight, greater flexibility, and better emergency capability. This ongoing program is a combined effort to bring alkaline and acid-based technology to a level of technology readiness demonstration in a sub-system breadboard by 1984 and in an engineering model system by 1987. Hardware will then be made available for testing in the electrical power system test bed.

The effort planned for FY 1987 through FY 1989 represents an advanced concept regenerative H_2O_2 fuel cell system having improved life and efficiency and reduced weight over the system for the initial Space Station. The advanced RFC is expected to contribute significantly to the evolutionary Space Station.

The NiH_2 bipolar battery concept has been recently demonstrated. The bipolar concept resulted from the integration of bipolar fuel cell stack technology with nickel electrode batter technology. With improved performance over individual pressure vessel (IPV) batteries, the bipolar battery with a common pressure vessel (CPV) offers greater volumetric energy density, reduced weight, much simpler high-voltage systems, and allows active cooling similar to fuel cell technology.

This bipolar battery concept is proposed for the advanced development program. Components and battery subsystems demonstration and endurance testing will be shown. Integration and testing of the battery will be done in the electrical power system test bed.

The goal of the bipolar NiH_2 battery development program is to demonstrate successful performance by mid-1986 at level 4 (short stack, flight-size hardware). Bipolar NiH_2 batteries will be ready for design, fabrication, and testing of level 5-type units (15 to 25 kW modules) in a breadboard system test by 1988.

Recent evaluation of an inertial energy storage system testing has shown significant potential for round-trip energy efficiencies of 85%. This performance coupled with a realization of long life wheel/bearing subsystems would provide significant reductions in total weight to orbit and corresponding reduction in total costs, especially when integrated width attitude control equations. Energy densities should be greater than 40 WH/KG. MSGC proposes to develop an inertial subsystem, based on presently developed wheel technology, in conjunction with electrical power system test bed activities.

7.3.4 Power Management and Distribution

Technologies presently being evaluated for the initial and growth stations are (a) power distribution by means of high-voltage DC or by high-voltage/high-frequency AC and (b) power control using automated selection of sources and buses for optimum operational capability. Development of Bulk Power Transfer Devices (BPTD's) and Remote Power Controllers (RPC's) is needed to ensure a successful design. Supporting a 1987 Phase C/D for Space Station will require upgrading existing programs and beginning new ones.

The tasks proposed will provide the RPC's and BPTD's needed for the power management and distribution system.

The complexity of an electrical power system capable of supporting the Space Station necessitates the use of an integrated electric power systems test bed. Such a test bed is required to evaluate concepts and hardware in a system environment and as a working part of a system similar to that of the actual station.

The basic structure and layout of the test bed will be planned to accommodate known Space Station requirements, but with the flexibility to accommodate changes, new concepts, and candidate hardware and with growth capability to allow expansion in advance of the normal Space Station evolution. The test bed will provide necessary data for establishing the baseline Space Station power management and distribution system design and hardware requirements, evaluating options, and performing trade studies. Ongoing technology will be incorporated as it becomes available and will be evaluated using the test bed for possible inclusion in the system design. Evaluation objectives are (a) AC versus DC distribution; (b) optimum voltage and/or frequency for the distribution system; (c) DC-to-AC inversion for high-frequency AC distribution; (d) DC regulators and conditioners; (e) bus and wire options; (f) auto- mated power system management and attendant control and instrumentation techniques; (g) four-quad, bidirectional battery changing and conversion; and (h) cycloconverters. In addition, new designs germane to the Space Station distribution system, such as rotary power transformers (BPTD's) and power switches (RPC's) will be initially tested in component breadboards then incorporated into the electrical power system test bed. A variety of tests is planned to determine (1) Power quality; (2) system efficiency and losses; (3) source and magnitude of power perturbations; (4) extent of automatic and manual modes of system control; and (5) system interactions.

7.4 THERMAL SYSTEM TEST BED

The Thermal Management System (TMS) that ultimately will be designed into the Space Station theoretically could range all the way from a Shuttle-vintage Freon system to an advanced two-phase heat-pipe-based design with hybrid combinations in-between. A credible evolutionary Space Station TMS could gradually transition from a conventional pumped fluid design to an advanced configuration as mission requirements expand and improved TMS technology becomes available. The basic requirement for such a buildup approach is that the heat transport lines (or plumbing) in the initial Space Station be oversized as required to accommodate two-phase flow for the full-capacity Space Station configuration. The resulting weight penalty for the initial Space Station would be quite acceptable because plumbing generally is a small fraction of the total TMS weight.

The TMS Test Bed will be designed to evaluate an evolutionary Space Station concept. This approach has several merits: (1) A reference data base will be established for conventional pumped fluid systems as a logical "point of departure" for subsequent comparisons with advanced development designs and (2) a broad data base of options will be established for objectively selecting a TMS design approach that is optimum for an evolutionary Space Station program. Obviously, if as anticipated, the two-phase heat pipe technology performs in a superior fashion during the TMS Test Bed activities, there will be specific substantiating performance and risk data to confidently recommend baselining the two-phase heat pipe approach for the initial Space Station without transitioning from a Shuttle-vintage design. On the other hand, if an evolutionary approach appears to be required, the specific data will exist to allow a system to be designed so that it can accommodate the future growth required.

The overall approach of the thermal test bed project first involves establishing a low-cost capability using existing test facilities and an extensive inventory of existing Orbiter Freon system and RTOP thermal technology hardware. The heat transport plumbing will be sized to accommodate two-phase flow conditions. Initially, the test bed heat transport circuit will contain liquid Freon that will allow establishing baseline data and system-level data for the ongoing space-constructable heat pipe radiator and radiator contact heat exchanger technologies. As two-phase transport circuit technology developments achieve a "ready" state, they will be integrated into the TMS Test Bed. The heat transport circuit will be reserviced using candidate on-orbit procedures to convert the test bed from a single-phase to a two-phase fluid configuration or thermal bus. The initial two-phase thermal bus would utilize Freon. A subsequent reservicing would substitute the more efficient ammonia working fluid as the technology matures. Following incorporation of the baseline thermal bus, the TMS Test Bed will be maintained and upgraded as required to provide integrated test support throughout the evolution of the Space Station Program.

The thermal test bed will be designed to operate in a sea-level laboratory environment and to support occasional thermal-vacuum tests. The vase majority of the testing is anticipated to be at ambient sea-level conditions with only specific thermal-vacuum tests. Experience with the Orbiter and space-constructable heat pipe radiator technology development has proven sea-level testing to be a very viable and cost-effective means of evaluation prior to a more costly integrated thermal-vacuum performance demonstration. The thermal bus technology development program will also make extensive use of sea-level testing, with thermal-vacuum testing only when mandatory.

The test bed will be configured with (1) Multiple parallel and series flow paths to assess temperature control performance and system stability for different steady state and transient heat load combinations; (2) a variety of fluid-to-fluid heat exchangers, two-phase evaporators, coldplates, and contact heat exchangers to assess thermal interfaces between different heat sources and sinks; (3) several competing fluid disconnect designs to evaluate TMS maintenance and modular growth approaches; (4) fluid swivels or similar devices to establish viable techniques for fluid transport across rotating or structural joints; and (5) an automated control system that will allow evaluation of a variety of control and fault/isolation techniques. A total heat load capacity of about 25 kilowatts has been chosen tentatively for the test bed because (1) It provides an excellent point of reference since 25 kilowatts approximates the capacity of the current Shuttle active thermal control system and the ongoing thermal bus development hardware and (2) a 25-kilowatt system represents a reasonably large-scale test article that should produce results that can be confidently extrapolated to a full-capacity 100-kilowatt flight system. A key feature of the TMS Test Bed will be its palletized configuration to streamline test setup and checkout activities. The pallet concept will also allow efficient transport of the test bed between ambient and thermal-vacuum chamber facilities as required. The pallet concept could also be adapted to support future flight experiment opportunities.

The thermal test bed project will maintain a high level of industry involvement during the evolution of the TMS Test Bed to encourage a competitive environment in the thermal control community before commitment to a Space Station flight hardware program. Industry will be encouraged to maintain TMS-related internal research and development (IR&D) tasks because the test bed will provide an excellent opportunity for them to gain (1) Early insight into how well their hardware technology integrates into the total system and (2) NASA acceptance of their technology enhancement ideas.

7.5 ATTITUDE CONTROL AND STABILIZATION SYSTEM TEST BED (TBD)

7.6 AUXILIARY PROPULSION SYSTEM TEST BED

Because of the current uncertainty in the Space Station configuration and the attendant uncertainties in propulsion system requirements, maintaining alternative propulsion system options is desirable. To maintain a degree of flexibility and to insure for the consideration of advanced propulsion technologies, three categories of propulsion systems will be pursued for development, test, and evaluation in the test bed(s). The three categories to be considered are as follows:

a. The earth-storable systems

b. The thermally augmented systems

c. The cryogenic hydrogen/oxygen (H_2/O_2) systems

The following sections will identify why each propulsion category is being considered, what its limitations are, what major issue/problem area will be explored in the test bed, and what analytic support is required. Because of the technical maturity of the earth storable systems, no advanced development test bed activity is required for them. The thermally augmented systems and the H_2/O_2 systems offer major potential program benefits and are less technically mature, requiring serious test bed evaluation.

7.6.1 Analytical Support and Studies

Analysis support will be provided to (1) develop and evaluate cost effective propulsion system configuration options for early test development; (2) evaluate and define test bed development requirements for evolutionary Space Station propulsion systems; and (3) develop computer models of candidate propulsion systems to support test program design and data evaluation.

7.6.2 Earth Storable Systems

The earth storable systems include two major candidate concepts: the monopropellant hydrazine systems and the hypergolic bipropellant systems (hydrazine family fuels/N_2O_4). The earth storable systems are considered the most advanced state-of-the-art concepts. Bipropellant systems were used on Gemini and Apollo and are currently being used on the Space Shuttle. Monopropellant hydrazine propulsion systems have flown routinely on planetary spacecraft and on a variety of earth satellites. Both concepts represent a relatively low initial cost investment. The monopropellant system, with its higher consumables requirement, must be traded off against the somewhat greater cost, complexity, and increased logistics of the bipropellant systems. Both concepts can meet a wide range of thrust-size requirements. The only area of possible concern with the monopropellant thruster is catalyst bed life.

Existing demonstrated catalyst bed life may be adequate to meet Space Station requirements. If not, a promising catalyst bed retention concept that could significantly improve bed life is being evaluated by industry. Because of the advanced state of the art of hydrazine systems, no advanced development test bed work is being proposed in this area. Any problems that arise during development of these systems are believed to be resolvable during the program development phase with no major cost or schedule impact to the program.

7.6.3 Thermally Augmented Systems

The thermally augmented systems employ thrusters wherein the working fluid is heated by an external source before its expulsion through the thruster nozzle. The advantage of this category of system is that it provides improved performance with monopropellant or cold gas systems and makes their performance more competitive with the more complex bipropellant systems. For example, hydrogen heated to 1600°F will provide twice the performance of current hypergolic bipropellant systems. Hydrogen is particularly attractive because it may be available as boiloff otherwise lost from the Orbital Transfer Vehicle (OTV) servicing when incorporated on the Space Station. Similarly, heating the effluent from a hydrazine monopropellant thruster can substantially increase performance. The major limitation for these augmented systems is thrust size, which is governed by the power available for thermal augmentation. Low thrust levels are currently being tested by the aerospace propulsion industry. Both hydrogen and hydrazine thrusters employing electrical augmentation have been tested in the 0.1-pound thrust range. Thrusters up to the 5-pound size range that would require only approximately 1 percent of the station electrical energy supply could possibly be used. The technical challenge relative to thermal augmentation is to develop an energy storage concept that would provide energy at high power levels for relatively short durations of thruster operation. Studies will be conducted to analytically evaluate thermal augmentation techniques for both hydrazine and hydrogen thrusters and the most promising concept(s) will be selected for component-level and then system-level test evaluation in the test bed. Because of the variable pulsed power requirements of the augmented concepts, very close coordination with the power systems test bed will be maintained.

7.6.4 Hydrogen/Oxygen Systems

The hydrogen/oxygen systems are being considered for the Space Station for two reasons. First, they provide a modest performance increase over the earth storable systems, which reduces propellant resupply requirements. Second, and perhaps more importantly, the propellant supply may be integrated with other hydrogen and oxygen users. This becomes more significant when the Space Station becomes a resupply depot for hydrogen/oxygen fueled upper stages. As with the thermally augmented systems, the hydrogen/oxygen systems are not state of the art in the size range and duty cycle applicable to a Space Station. Low pressure concepts (under 100 psia) require heat exchanges to condition cryogenic propellants before their introduction to the thrusters. Propellant conditioning components of an appropriate size are not available, but can be designed and fabricated once system requirements are better defined. Low pressure thrusters fall into the same category.

High pressure H_2O_2 systems (above 250 psia) require not only heat exchangers for propellant thermal conditioning, but turbopump and/or turbocompressors for pressurization as well. Low pressure H_2/O_2 systems offer higher performance than high pressure H_2/O_2 systems because they do not have parasitic conditioning and compression requirements. Initial plans are to explore only the low-pressure H_2/O_2 system in the test bed.

The critical components for testing a low-pressure system are planned for advanced development. Testing of the components will be conducted to identify component performance as well as component interactions. Iterations will be made in component designs where test results indicate they are needed. Testing of this low-pressure concept will continue into the system level and through the design portion of the program Phase C/D as appropriate. As with the thermally augmented system concepts, the hydrogen/oxygen concepts integrate closely with the Power and ECLS Test Beds. Depending on the extend to which the propulsion system is integrated with the overall station, the propulsion system candidates could be updated with time; i.e., evolve to more advanced systems. If the propulsion system is modularized, the initial module could be replaced at any time with any more advanced type of system. Even with substantial iteration, a simple hydrazine system could evolve to a high performance augmented hydrazine system.

7.6.5 Critical Components

Following is a list of potential components/subsystems that may be designed and fabricated for test bed evaluation:

- GO_2 - GH_2 Thruster: A 30 pound thrust rocket engine will be analyzed. The thruster will include valves, injector, igniter, chamber and nozzle.

- O_2 Passive Thermal Conditioner (Waste Heat Source): A component will be analyzed which accepts and stores heat from a waste heat source at near earth ambient temperatures as latent heat in a melted substance. This component can then provide larger quantities of stored heat upon demand to thermally condition cryogenic oxygen to near earth ambient temperature gases.

- H_2 Passive Thermal Conditioner (Waste Heat Source): A component will be analyzed which utilizes heat from a waste heat source at moderate temperatures, possibly the thermal control system radiator. This component can provide large quantities of heat to thermally condition cryogenic hydrogen for use in O_2-H_2 gas-gas thrusters or in moderate temperature hydrogen gas thrusters.

- O_2H_2 Passive Thermal Conditioner (Spacecraft Structure Heat Source): A tube type heat exchanger which would be attached or integral with structural members would be analyzed which would utilize the sensible heat inherently available in structural members of pressure vessels. This passive heat exchanger could vaporize cryogenic hydrogen and/or oxygen and thermally condition to near earth ambient temperature utilizing the structure sensible heat which would then re-heat from solar input.

- GO_2/GH_2 Gas Generator/Heat & Exchanger: A small GO_2/GH_2 combuster would provide effluent gas for a heat exchanger to condition cryogenic oxygen and hydrogen to near ambient temperature gases. The gas generator heat exchanger concept will be analyzed. The decision to fabricate the gas generator/heat exchanger will be made only of the results of design studies identify a need.

- GO_2/GH_2 Pump/Compressor: A pump or compressor will be analyzed, designed and later fabricated depending upon the need to boost the pressure of cryogenic liquids (hydrogen or oxygen) or GO_2/GH_2 gaseous boiloff products in the system concept most desirable for Space Station. The decision to fabricate the pump/compressor will be made only if the results of the design studies identify a need.

- N_2H_4 Resistojet: A hydrazine thruster in the thrust range of 0.1 to 0.5 pounds will be analyzed. The assembly will include power processor.

- High Temperature (1600°F) Passive Thermal Conditioner For H_2: This component accepts pre-vaporized and partially thermally conditioned cryogenic hydrogen. It provides additional temperature conditioning by supplying stored heat to the propellant from a metallic salt or other substance which has been heated to a temperature above its melting point.

- Hydrogen Resistojet: A hydrogen thruster in the thrust range of 0.1 to 0.5 pounds will be analyzed. The assembly will include a power processor.

7.7 SPACE OPERATIONS MECHANISMS TEST BED

The Space Operations Mechanisms Test Bed will provide a vital link between discrete mechanism technology at the component or subsystem level and the integrated system level mechanism technology required for the Space Station design and operation. The test bed will have a pivotal role in gathering of mechanism technology, focusing the appropriate technology on the evolving Space Station requirements, and evaluating candidate mechanisms in an integrated fashion with other Space Station system requirements. The ultimate objective of the test bed will be the selection of those mechanism technologies which provide the required integrated system performance while having either minimum or reasonable development risk.

A gamut of mechanism devices and technologies must be developed and evaluated for Space Station applications. Typical Space Station mechanism applications include the following:

- Assembly and exchange of major elements;
- Erection/deployment/pointing of panels, radiators, etc.;
- Assembly of structural beams;
- Active shape control of large distributed members;

- Servicing/repair/assembly by means of OMV free flyer;
- Servicing and repair by attached arm;
- Orbiter resupply flights;
- OTV missions;
- Crew transfer between major elements; and
- Antenna/telescope/sensor pointing control.

Various classes of mechanisms required to perform these applications include berthing mechanisms, latching devices, manipulators, mechanical joints, adaptable/programmable actuators, pneumatic devices, rotary and linear actuators, electrical and fluid couplings, etc.

The mechanisms test bed capability will consist, primarily, of a computer-controlled, hydraulically-powered Six Degree-of-Freedom (6 DOF) Motion System and a 4,000 square foot air-bearing floor which are geared to promote candidate mechanism technologies by system level evaluations. It is recognized that Space Station mechanism operations will be highly interactive with other systems which, in turn, will change their characteristics during initial assembly of major elements, erection of panels, repair, and certainly with Space Station evolution. Mass properties and momentum characteristics are obvious drivers for mechanism performance, but interface with vehicle dynamics, control systems, and man/machine interplay can have substantial influence as well. Mechanism technology must account for the effects of all of these interfaces by detailed system design or else the mechanisms must be adaptable to the point that their performance is transparent to external influences. Since the 6 DOF Motion System is computer driven, system interactions are readily provided by means of math modeling and programming. Mass properties, control system characteristics, and relative vehicle dynamics are represented in a straight forward manner using computer programs. Where man/machine characteristics are required, they are provided by a test subject operating a simulator control station and responding to computer driven instruments and simulator video images.

Although the 6 DOF Motion System is computer oriented, it features a hydraulically-powered platform which provides six degree-of-freedom motion to mechanism test articles. The actions of the mechanism test article on its mating device or loads are measured in six degree-of-freedom forces and moments with a sensor having a 1kHz band pass. The platform is driven in a closed loop fashion to a relative position resulting from these measured forces and moments acting on the modeled mass properties, relative vehicle dynamics, control system, etc. This facility technique provides for the operation of a prototype mechanism in a manner very highly representative of its actual dynamics and loads under zero-g orbital conditions and with interactions from structural bending attitude control, and other Space Station systems. Although the facility provides only a single six degree-of-freedom motion, it does represent the general case of two objects moving freely in space. Since the equations for computer-controlled operation of the moving platform represent the relative positions between two free bodies in space, general motions of both bodies are indeed represented.

Long-term potential for the motion system test bed to support the evolutionary Space Station is considered excellent. Because the facility is computer driven, it can be easily modified by software to represent various Space Station configurations. In the same manner, it may provide mechanism operation which may have maximum forces in excess of 5,000 pounds. These force levels are determined by a force/moment sensor which simultaneously measures these dynamic variables in six degrees of freedom. It has a remarkable dynamic range of 1,000,000 to 1 and is based on a network of piezoelectric crystals and charge amplifiers.

Development and evaluation of deployable structures will be accomplished by the use of a 44 ft. x 86 ft. air-bearing floor. Deployable dynamics will be evaluated in simulated zero-g conditions by attaching prototype structures to air-bearing fixtures which can freely move in a horizontal plane over the polished, ultra level epoxy floor. Model characteristics of deployable light weight trusses will be determined while in simulated zero-g conditions. Joint damper mechanisms will introduced to control structural dynamics. Techniques will be developed for determination of structural characteristics while in orbit. Mechanisms for active, distributive control of model shapes will be evaluated.

Developmental and effectors and manipulators will also be evaluated in the air-bearing facility. Generic Space Station assembly and servicing tasks which will be candidate manipulator roles will be provided to assess and enhance this category of mechanism technology. General purpose facility computers will be used for interfacing and real-time control of these mechanisms. Manipulator control algorithms will be programmed on these computers and their capability will be evaluated while performing representative tasks such as module exchange, inspection, and assembly or erection of Space Station elements. These tasks will be performed with typical lighting conditions, representative video viewing, and generic remote control stations.

Fulfillment of the role expected of the Mechanism Test Bed will ultimately be determined by the success in selection of advanced mechanism technologies which are developed into an operational Space Station without technical flaws and without undo funding and schedule problems.

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BOOK 6

SYSTEM OPERATIONS

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BOOK 6

SYSTEM OPERATIONS

Approved By:

JOHN D. HODGE
Director
Space Station Task Force

PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
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BOOK 6

SYSTEMS OPERATIONS DOCUMENT

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FOREWARD

This document, presenting the operations aspects of the Space Station program, has been developed through the cooperative efforts of the Space Station Operations Working Group, shown below.

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This document will not be updated following this publication. Section X will be republished as the Operations Requirements Document and will be subject to change control by the Space Station Task Force.

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1.0 INTRODUCTION

The Space Station System will provide a comprehensive capability to explore and exploit the space environment. Conceptually, it will include a permanently manned central base of operations and research and development (R&D) in low-Earth orbit (LEO). The Space Station and its associated spacecraft will be capable of performing scientific, technical, and applications missions for research, government, commercial, and national security customers. It will be Shuttle-supplied and will evolve by time-phased, delivered modular increments. The Space Station will serve as a laboratory and base for general space operations. Activities will include:

(1) Conducting on-board and attached equipment operations;

(2) Assembly and construction of large and complex payloads and space facilities;

(3) Mating of payloads and stages;

(4) Launch and recovery of payloads, Orbital Transfer Vehicles (OTVs), and Orbital Maneuvering Vehicles (OMVs);

(5) Test, checkout, and refurbishment of equipment;

(6) Propellant transfer and storage;

(7) Technology demonstration missions; and

(8) Servicing of co-orbiting elements of the System.

This document defines the operational approach for the Space Station System. Emphasis is placed on new operational factors that arise with the permanently manned orbital facility, means to operate the System in the safest and most cost-effective manner, and a customer-oriented, "user friendly," operational approach to achieve maximum benefits from the System. This document is intended to be a reference document from which operational requirements have been derived for the Space Station program. The ground rules and scenarios are given in Sections 2 through 9 and the derived operational requirements are given in Section 10 of this document.

2.0 OPERATIONS CONCEPT

2.1 SPACE STATION SYSTEM

The Space Station System (SSS) concept is under development. To permit discussion of an operational concept in this document, it is assumed that the initial increment of the Space Station System will include at least the following generic elements:

- A manned Space Station consisting of a utility module, research and development (R&D) labs, habitats, remote manipulating system(s), resupply modules, a multiple berthing adapter (MBA), Shuttle docking and berthing capability, orbital maneuvering vehicle (OMV) capability, and accommodations for attached payloads;
- One or more orbital platforms including one in near-polar orbit;
- An OMV that will have the capability of limited translation among the Space Station, co-orbiting platforms, and co-orbiting free flyers;
- Provisions for servicing payloads; and
- Ground systems to support the flight elements.

The assumed generic configuration does not constitute NASA or Space Station Task Force endorsement of a final baseline configuration.

The manned Space Station will be placed in approximately a 28.5° inclination orbit at an altitude of approximately 270 nautical miles (NM).

2.2 SPACE STATION SYSTEM OPERATIONS

Delivery of various Space Station system elements to orbit will be accomplished by the Space Transportation System (STS). Initial assembly, activation, checkout, and operational verification tasks will be shared by the STS in a Shuttle-tended* mode, the Space Station flight crew, and ground control.

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* Shuttle-tended is defined as that period of time when the Orbiter is docked to the Space Station or is in close proximity. Nothing more is implied.

Crew occupation will occur after the manned system is verified and will initially consist of a crew of up to 8 rotated totally or partially by the STS every 90 days. Expendables and spares will be carried to the Space Station in a resupply module by the Shuttle approximately every 90 days.

As demand dictates, it is envisioned that the Space Station System will expand by the on-orbit integration of new hardware including: Additional habitats and laboratory modules; attached payloads; additional equipment for servicing and repairing satellites; facilities for mating satellites to upper stages; protective storage facilities with environmental conditioning equipment for satellites awaiting deployment and satellite orbital replacement units (ORU's) prior to utilization; and provisions for basing, servicing, and maintaining upper stages. Long-term operations may include 10 or more Space Station, mission, and/or payload specialists and other customer personnel such as guest scientists. Operations will continue to include Shuttle-tended modes for transfer of equipment to and from the Space Station System, possibly including cryogenic propellants. Propulsive stages based at the Space Station will provide the necessary orbital maneuvers to bring satellites or platforms that do not provide their own propulsion into the proximity of the Space Station for servicing. An OTV will be based at the Space Station to provide the delta velocity necessary to transfer payloads to and from different orbits.* Manned maneuvering units (MMUs) will provide extravehicular activity (EVA) mobility within the region surrounding the Space Station. The Space Station also will have significant and growing functions involving logistics, information control and processing, and proximity traffic control. Since the Space Station System will be placed in orbit to operate for years with minimal ground support, a major design challenge of the program is to "build in" operability, reliability, maintainability, and logistics support.

Management of the Space Station System will divide operations between the flight and ground portions of the system so that the capabilities of each are most effectively utilized. System autonomy will minimize ground control of the Space Station. On-board machine autonomy will minimize crew involvement

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* One or more OMVs may subsequently be GEO-based to service GEO satellites.

in system monitoring allowing the crew to maximize high return activities in support of customer missions. The Space Station will provide non-mission unique basic services such as course instrument pointing. Customers will arrange for appropriate mission-unique services.

In order to provide a framework for the operational approach, the following ground rules are established.

2.2.1 Safety Ground Rules

(a) Pre-planned operations and design will provide safe haven/safe retreat provisions isolatable from the rest of the Space Station and capable of sustaining the flight crew for 22 days (see section 5.2.5). Provisions will be made for crew transfer from each safe haven to the orbiter.

(b) As a minimum, a fail-operational/fail-safe and restorable levels will be provided in safety-critical systems within the manned Space Station and on elements of the System.

(c) Emergency equipment including fire suppression, life support, and medical will be provided within the manned Space Station. Safety and first aid training will be provided for all crew members.

(d) Critical systems will be capable of undergoing maintenance without the interruption of critical services and will be "fail-safe" while being maintained.

(e) A caution and warning system within the Space Station will be provided.

(f) Ground and on-orbit operations will provide safe protection for the storage, handling, transportation, processing, launch, use, disposal, and clean-up of flammable, combustible, and hazardous materials.

(g) Flammability, odor, and off-gasing requirements will be established for materials on the Space Station.

(h) Operations and Systems design will provide protection from internally and externally produced radiation/EMI.

2.2.2 Operational Ground Rules

(a) The Space Station System will develop in an evolutionary manner over a period of years. Growth capability will be a major operational and design consideration.

(b) The Space Station is intended to be manned unless unforeseen circumstances force evacuation.

(c) The System will operate in Shuttle-tended modes for material and crew resupply, for delivery of Space Station elements, and delivery /return of payloads.

(d) Design and operations will use the Space Station flight crew for the performance of tasks where man's capabilities provide a cost-effective alternative to automation.

(e) Management of Space Station System operations (both manned and unmanned elements) will be divided between on-board and ground systems to most effectively utilize the capabilities of each.

(f) Communications between the ground and the Space Station System will be through the Tracking and Data Relay Satellite System (TDRSS) or its replacement system.

(g) The training program will prepare the flight crews and ground support personnel for normal and off-nominal operations of the elements of the Space Station System.

(h) Training for the accomplishment of specialized activities will be provided for the crew. Adequate cross training will be provided to allow backup operation of critical systems.

(i) Extensive preflight training will not be done for infrequent tasks (time critical emergencies excepted). On-board training aids will be provided to assist in accomplishing these functions. Any crew training time for customer activities will be negotiated with the customers and not artificially limited by this ground rule.

(j) On-board flight operations will nominally be conducted 24 hours a day, seven days a week.

2.2.3 Operability Ground Rules

(a) Since systems will be maintained on-orbit, reliability, maintainability, and logistics support will be prime considerations in design of the System.

(b) The Space Station System and its subsystems will have the capability to be progressively upgraded on-orbit as improved technology becomes available. However, any upgrading of the Space Station System or its subsystems will maintain service commonality with customer applications in existence or under development to the maximum extent possible.

(c) Continuous subsystem monitoring and control by either the flight crew or ground will not be required for normal Space Station System operations. Space Station System subsystems will be designed such that any single credible failure will result in a safe condition. Subsequent crew action may be required to restore normal Space Station System operations.

(d) The capability will be provided to progressively automate subsystems as procedures are developed in order to achieve a high degree of automation. The flight crew or ground will be able to modify, generate, add, or delete application* software in real-time with the System on-line using the Space Station control consoles.

(e) *A single test and control operations* language *(as opposed to a* general purpose programming language such as ADA and FORTRAN) will be used to generate and sustain the application software for ground integration, ground test, ground operations, and on-board operations. This language will be used by Space Station System and subsystems and will be made available as an option for customers.

(f) A single operational data base for Space Station System operations will be maintained as it evolves through the life cycle of each Space Station element. This data base must provide the storage and retrieval capability for functions such as crew procedures, vehicle procedures, library, data archives, mission planning, crew planning, inventory/logistics, medical records, mail, crew entertainment, and provide for logistics maintenance related activities and expert systems support. This operational data base will describe the element and its operation in terms of command/data formats, alarms, limits, conversions, display formats, failure history, etc., will provide for a limited life (time/cycle) accountability, and will become part of the flight and ground, on-line and off-line, single operational data base.

(g) Capability for real-time data base modification with the System on-line by the flight or ground will be provided.

(h) The capability to conduct near-term activity planning will be provided on-board the Space Station with long-term planning provided on the ground.

(1) Near-Term Planning - Planning of daily activities for which information is available on-board including replanning when circumstances have made previous plans unworkable (e.g., failures, experiments, general housekeeping tasks, subsystem status checks, preventive maintenance, and consumable inventory).

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* Application software is that software which is resident within the Space Station computers to monitor and control Space Station subsystems and performs special operations tasks.

(2) Long-Term Planning - Planning that requires the consideration and integration of numerous facts and requirements to which the flight crew may not have access (e.g., resupply requirements, crew rotation, delivery of new payloads, and retrieval/servicing missions).

(i) Orbital replaceable units (ORUs) will be designed for ease of on-orbit replacement. The hardware will be designed or integrated to use common fasteners, connectors, and tools and to utilize common packaging as appropriate.

(j) Procedures and operational system/subsystem documentation will be available in real-time through on-board, interactive, tutorial computer storage in order to reduce or eliminate the need for on-board paperwork. Portable on-board terminals will be provided.

(k) Hardware and technology commonality will be applied to the design of on-orbit replaceable hardware to simplify the logistics and maintenance activity and to minimize program costs. This commonality applies to ground and flight hardware and software alike. Commonality will also reduce spares storage.

(l) Subsystems will be as functionally, electrically, mechanically, and electronically independent as practical to facilitate maintenance, control, fault management, evolvability, and testability.

(m) An on-board function will be provided for unscheduled maintenance of the Space Station System which includes OMV/OTV and customer systems. The capabilities of this function will support the repair level determination of the Space Station System and customer ORUs.

(n) ORUs may be replaced by intravehicular activity (IVA) and EVA or by teleoperation/robotics. The EVA ORUs must meet design safety requirements for a suited astronaut and provide the means to perform the changeout.

(o) EVA operations will be allocated as a limited resource, and Space Station System design and operations will allow for judicious use of this resource.

(p) Based on allowable downtime, storage space availability, criticality, and reliability considerations, one or more on-board sets of spare ORUs will be provided. However, customer ORU sparing provisions will be left to customer option consistent with safety, storage capability, etc., constraints.

(q) The System will be designed so that the need for extensive flight crew training is minimized.

(r) Design will be such that procedures can be standardized for many types of system activity.

(s) Predefined interface standards identical to or compatible with generally established space standards will be used between Space Station elements (e.g., platforms, core, ground, free flyers, etc.) and as appropriate between subsystems.

(t) Crew time will be allocated as a resource. For operational and design purposes, it will be assumed that:

(1) During any 24-hour period, EVAs will be limited to 8 hours maximum per EVA crewmember.

(2) Nine hours per day per crewmember will be available for Space Station System and customer operations.

(3) Each crewmember will be available for Space Station System operations 5 days per week.

(u) A configuration management system will be established to track and maintain the current configuration of each element's hardware and software and the electrical, structural, fluid, and mechanical subsystems. Such a system will be accessible by on-orbit crew and by ground personnel through the system data base.

2.3 MISSION OPERATIONS

A mission is defined as a time sequenced set of events for a specific customer. Mission activities will include operating and servicing internal and externally-attached experiments/payloads/laboratories, servicing the platform-mounted experiments/payloads, servicing of free flyers, test and development of payloads and upper stages, and eventual large-scale construction/assembly of payloads. The Space Station will operate cooperatively with the co-orbiting platforms with their attached instruments, experiments, and payloads by providing material collection and system/instrument replacement and refurbishment. System monitoring, data collection, and control will be provided on a mission-unique basis and as required for proximity operations. Studies are underway to define specific initial and long-term capability.

Possible missions for the Space Station System are:

- Operation of small, self-contained payloads within the Space Station;
- Conducting more extensive investigations within the Space Station such as life science and microgravity experiments;

- Servicing and monitoring instruments for Earth and space viewing and other purposes on the Space Station;
- Operation of Station-attached materials processing facilities;
- Operation of experiments and equipment within pressurized laboratory modules;
- Operations conducted with tethered payloads;
- Servicing and repair of free flyers (this may include storage of satellite spares, components, and fluids at the Space Station);
- Cooperative operation of instruments on the co-orbiting or tethered platforms where benefits can be gained through manned interaction or advantage taken of the proximity for data gathering;
- Servicing and repair of the platforms and attached instruments including the disposal of removed parts of payloads through use of the OMV, MMUs, EVA while a platform is berthed to the Space Station, and periodic payload changeout;
- Mating of payloads to upper stages and testing and deployment of the mated payload/upper stage;
- On-orbit spacecraft assembly and test;
- Basing of upper stages including maintenance, servicing, repair, propellant loading, deployment, and tracking/monitoring;
- Assembly, construction, and testing of very large structures such as antennas or imaging systems;
- Preparation of samples and products for Earth return;
- Payload retrieval; and
- Zero-g man/system simulations with the Space Station.

The System will be operationally responsive to customers. It will provide unique opportunities to pursue mission activities in space with "man in the loop." Customers will benefit from the capability for close interaction between the crew and customer such as in-place calibration, modification, data integration, instrument selection and adjustment, pinpointing of targets of opportunity, and on-hand witnessing of processes. To achieve maximum benefits, the operational System will provide a high degree of customer interaction with the mission, further enhancing the effectiveness of the flight crew to the customer. When required, the customer will provide payload specialists for specific missions. Space Station data systems for payloads will be transparent requiring minimum customer interaction for data reconstruction. Payload Operation Control Centers (POCCs) will command and monitor payloads independently, subject to safety and compatibility constraints. The operational approach will be planned to reduce requirements placed upon customers by minimizing the number and complexity of interfaces, maximizing customer involvement, and avoiding unnecessary duplication of operations for payloads. Operations and design will provide a "user friendly" system to facilitate on-board operations by scientists or payload experts without specialized Space Station training. The customer must perceive that the System is not only beneficial, but also economical, dependable, available, and flexible.

The following customer operations ground rules are established:

(a) Experiment/payload operations at the Space Station and within the System will include the capability for a high level of customer participation and responsibility.

(b) System operations for experiments and payloads will place a minimum number of requirements upon customers. Requirements will be limited to those necessary for safety and customer compatibility. Requirements will be completely documented in an easily accessible and understandable manner.

(c) The Space Station System and its operations will provide simple, standard, stable requirements and interfaces for its customers.

(d) The Space Station System will provide non-mission dependent basic services and will be compatible with payloads providing their own services such as computation and communication.

(e) The System will be designed and operated so that the flight crew will have the ability to change planned activities in order to capture time-critical data from unexpected events.

(f) The Space Station crew will consist of a mix of Space Station, mission, and payload specialists. The skill mix will depend on anticipated mission activities.

(g) Operations and design will provide a "user friendly" System to facilitate on-board operations/maintenance by scientists or payload experts with a minimum of Space Station specialized training.

(h) Capability will be provided for direct communications and independent customer operation and monitoring of payloads including POCC-to-payload command and monitor consistent with safety and customer compatibility constraints.

(i) Flight and ground data systems supporting payloads will be transparent to the customers.

(j) The Space Station command and data handling system will be capable of secure communications as required for normal and emergency operating conditions. The command link will employ command authentication.

(k) Payloads requiring secure commanding and data handling (either commercial proprietary or national security) will be responsible for command and data encryption and decryption within the payload and on the ground.

(l) Space Station System housekeeping and engineering data for transmittal to the ground will be functionally separate from the payload data. This will allow faster data separation and will help ensure against unauthorized distribution of proprietary data.

(m) Payloads to be serviced by the Space Station will be provided service standards by the Space Station program.

(n) Message management techniques will be employed so that data for individual customers will be functionally separate.

(o) Allowable service interruption criteria will be negotiated and established for customer critical systems and will be implemented through redundancy, maintainability, and/or cost policy provisions.

2.4 GROUND CONTROL/SUPPORT OPERATIONS

The various configurations the Space Station System will go through during its buildup will require different levels of ground control/support. Ground support will be provided for the platforms, OTV, OMV, and the Space Station in the form of flight and system monitoring and assistance during the assembly, activation, checkout, and verification of each new System element. Ground support will continue until confidence is achieved in the System's element operation. Subsequent ground monitoring will be limited to periodic review of data; however, voice communication support from the ground control facility will be provided when the Space Station is manned.

Mission planning activities for attached payloads may be done on the ground and/or by specialists on-board the Space Station. The ground may also have primary control of the attached payloads or it may be shared or totally controlled by the on-board crew. Blocks for payload time lines will be allocated to the customers for scheduling. Integrated time line activities will be developed through iterations between the on-board crew and the ground including the customer. The integrated time line will be maintained by the shared on-board/ground data management system and either the ground or on-board crew will be able to change the time line.

The ground control facilities (e.g., POCC's) for the payloads will be dedicated to support for a specific mission. They are reconfigurable and are modified as required for various payloads. The payload ground control facilities will provide for autonomous operations consistent with the above since they are separate from the ground support facilities for the Space Station. The payload support facilities will support payload checkout and performance monitoring, payload mission time line planning, and a limited amount of payload data processing. Customers may furnish their own, separate payload control facilities.

Flight crew training will prepare them for the following tasks, as required:

- System monitoring and maintenance;
- Emergencies (including medical);
- Propellant handling;
- Construction/assembly;
- EVA, OTV, and OMV operations;
- Payload and experiment operations;
- Mission activity planning including scheduled and unscheduled maintenance; and
- Daily routine tasks.

Training for ground support personnel will prepare them for the following tasks:

- System performance evaluation;

- System troubleshooting;
- Payload and experiment interface operations;
- Mission activity planning; and
- Failure analysis.

Ground control will make maximum use of CAD/CAM technology in establishing simulated designs for Space Station elements such that the effect of real-time decisions can be analyzed quickly for overall impact on the Space Station before implementation. The following ground control ground rules are established:

(a) Ground control/support functions will include STS, Space Station, platform, payload control, OMV, and OTV operations.

(b) Ground control will initially provide for System monitoring and support. Then it will significantly reduce the real-time monitoring as the System becomes operational. Allocation of functions (from ground to flight) will follow a planned phaseover as operations mature.

2.5 PRE-LAUNCH GROUND OPERATIONS

Ground operations necessary to support Space Station System integration and checkout during both the initial establishment of an on-orbit System and the operational era include element verification, interface verification, interaction with the STS and ground systems, element refurbishment and reflight, payload ground operations, and ground support of on-orbit operations. The primary objective of the Space Station System ground operation verification process is to assure that the integrated flight and ground systems satisfy the applicable requirements. This objective will be accomplished by demonstrating that the performance of the combined Space Station subsystems, elements, payloads, and ground support equipment (GSE) meet established requirements and that related interfaces are compatible and functional. The result of each complete pre-launch ground operation process will be a launch-ready assembly of components, subsystems, and System elements in the desired configuration. Subsequent to the initial establishment of an on-orbit System, interface verification will present a unique operational challenge in that the System will be on-orbit before some elements and payloads are fabricated. This will preclude any possibility of a ground physical interface integration test. A capability will be developed to verify new interfaces and procedures to ensure their proper operation on-orbit and to demonstrate end-to-end system operability and maintainability. GSE and facility capabilities, compatible and consistent with applicable safety practices and documents, will be provided to support Space Station System element handling, assembly, and checkout requirements. These facilities will maximize commonality of hardware and software with each other and with the operations facility.

An integrated logistics system will be developed and maintained to support maintenance, provisioning, inventory management, and other logistics-related activities in support of flight and ground operations.

The following ground operation ground rules are established:

(a) Prelaunch operations will provide for servicing/deservicing of all elements/payloads and for verification that systems are launch-ready, including form, fit, and function verification testing to minimize on-orbit incompatibilities.

(b) Maximum use will be made of flight system capability to reduce the requirements for ground support equipment (GSE) and other support during ground testing of Space Station System flight systems.

(c) An integrated system ground test will be made of the initial Space Station.

(d) Physical and functional interfaces among each Space Station element, subsystem, and component, and between each payload and the Space Station will be demonstrated as compatible and functional before being committed to launch.

(e) An integrated logistics system will be established.

(f) The capability to service/deservice consumables within the elements will be provided. The capability to install and remove hardware within the elements will also be provided. These requirements will also include the capability for late access to the elements at the launch pad where required.

(g) The capability to install elements into the STS (horizontally or vertically), remove elements (horizontally or vertically), troubleshoot returned elements, remove failed components, and install replacement components will be provided.

(h) A verification program will be provided to assure that all modifications and upgrades function properly.

(i) Prelaunch operations and associated facilities and equipment will provide for STS reconfiguration, processing, and launch within 19 days (see Section 5.2.5) of notification in support of a Space Station rescue mission.

(j) The capability for on-Earth transportation of all Space Station System elements to/from any location will be provided.

3.0 ORBITAL OPERATIONS

3.1 SPACE STATION ORBITAL OPERATIONS

The Space Station System on-orbit flight operational concepts are critical to the overall design requirements for the various elements of the System. The goal of the operations concept is to be cost-effective while at the same time achieving a high degree of Space Station System independence (autonomy) from the ground. Operations philosophy and past experience require that the Space Station be Shuttle-tended while occupied without a redundant safe haven and a resupply module. The following scenario employs this philosophy.

3.1.1 Assembly And Activation

3.1.1.1 Manned Base

As previously described in Section 2-1, elements of the Space Station include the utility module, multiple berthing adapter (MBA), R&D lab, remote manipulating system, resupply modules, and habitat modules. The following is a scenario of a typical assembly and activation of these elements to illustrate the operational steps, concerns, and requirements that may be considered when defining the Space Station and selecting its possible evolutionary path.

First Shuttle Launch

The utility module will be the first element to be launched on-board the STS. Launch will be phased to result in an orbital phasing that provides the best subsequent launch opportunities. The Orbiter will circularize in a low-Earth orbit of approximately 270 nautical miles (nmi). The Orbiter crew probably will consist, as a minimum, of the commander, the pilot, and a mission specialist.

After circularization, the mission specialist will use the RMS to place the utility module in the berthing position. A crew member will enter the utility module and perform subsystem activation. After activation, the RMS will be used to deploy the utility module and the Orbiter will move away.

The ground will continue to monitor the performance of the utility module and its orbital decay. An orbital altitude adjustment may be needed on a periodic basis to maintain the module at the desired altitude.

Second Shuttle Launch

The second STS launch will carry the MBA and one habitat module. Crew for this launch will consist of at least the commander, the pilot, and the initial Space Station activation crew.

Shuttle ascent and launch azimuth will be targeted based on the previous tracking of the utility module. This second launch will be targeted for an orbit attitude such that the catch-up phase ends approximately 16 hours after lift-off. This is to allow the crew time to perform the several on-orbit maneuvers required for rendezvous with the utility module, configure and verify Orbiter system operations, and have the desired meal and sleep periods.

The Orbiter must have the proper sensing and tracking devices on-board so that there are no lighting constraints during final rendezvous phase. The ground will command navigation lights and any necessary flood lights on the utility module.

After the rendezvous has been completed, the Orbiter will assume a station-keeping position while the remote manipulating system (RMS) is unstowed and verified. Two RMS units may be required to perform the necessary tasks.

The RMS will be used to remove the MBA from the Orbiter and berth it to the utility module.

The manipulating system will maneuver the habitat out of the payload bay and into the proper attitude for berthing. Having achieved proper positioning, the Orbiter will move into close proximity (10 to 20 feet) to the utility module. The RMS will complete the final 10 to 20 feet of closure and berth the habitat to the utility module. The attitude control system of the utility module will maintain inertial hold during this critical phase of berthing. The Orbiter crew and/or the ground crew will need positive indication of berthing.

Upon confirmation of berthing, the manipulating system will be released from the habitat, and the Orbiter will translate away from the utility module and habitat configuration. At the time of berthing confirmation, an attitude control constant change may be required to account for the new configuration.

After the Orbiter crew and ground crew have determined that the new configuration is stable in attitude and the systems are performing satisfactorily, the Orbiter will again rendezvous with the Space Station. The Space Station ACS will be deactivated just before Orbiter berthing to assure no firings during this final maneuver phase. The Space Station attitude control constants will have to be changed upon confirmation of Orbiter berthing to the habitat module to accommodate the change in mass and inertia.

Immediately following docking, the Space Station ACS will be reactivated and the Orbiter system deactivated. The Orbiter crew and ground crew will monitor the stability of the new configuration before continuing. Two of the crewmen will enter the habitat module. The crew will turn on the lights, inspect all launches, and connect required umbilicals between the Orbiter and the habitat module and between the habitat module and the utility module. The environmental control and life support system (ECLSS) will be activated. The crewmen then will return to the Orbiter and close all hatches in preparation for the crew rest period. During this rest period, the ground will monitor the habitat module pressure stability and the ECLSS as well as the attitude stability of the entire configuration.

At the end of the rest period, the Space Station crew again will prepare to enter the habitat module. This workday will be used to complete system activation and reconfiguration of the habitat module, to unstow and move equipment and supplies, and for any other necessary activities. At the end of this work period, the crew will leave the habitat module configured for ground monitor and control after final Orbiter separation.

After the Orbiter undocks from the Space Station, the crew will make preparations for entry and landing.

Third Shuttle Launch

The third STS launch will carry a resupply module and a Space Station crew of four.

The Orbiter will rendezvous and dock with the Space Station. The resupply module will be removed from the payload bay by the RMS and attached to the MBA.

After the resupply module has been attached to the Space Station, four crewmen will transfer to the Space Station with their equipment. The Orbiter will undock and assume a station-keeping position after the Space Station crew completes necessary verifications.

After systems are verified, the Orbiter crew will separate and prepare for entry and landing, leaving the four Space Station crew members with the Space Station.

Fourth Shuttle Launch

The fourth STS launch will carry two R&D lab modules and up to four additional Space Station crew members. After rendezvous with the Space Station, the remote manipulator will be used to attach the R&D lab modules to the MBA and the Space Station crew will transfer. The Orbiter will then prepare for entry and landing, leaving the Space Station crew of up to eight personnel on-board the Space Station to complete the Station activation.

3.1.1.2 Platforms

Delivery of platforms will be accomplished by the STS. The Orbiter will be launched so that it can achieve the desired orbit. One of the platforms will be in polar orbit.

When the desired orbit is achieved, the Orbiter will remove the platform from the payload bay with the RMS. Depending on the design of the platform, several paths can be followed for activation. The assumed method is to attach the platform to a berthing structure in the Orbiter payload bay. In this position, the appendages of the platform will be deployed and systems activated. System verification of command and data links would be verified. Once platform systems are activated and verified, the RMS will remove the platform from the berthing fixture and release it to become a free flyer. The Orbiter will move to a safe distance while final system verifications are performed. If the Space Station is present, it will continue to monitor the platform, but prime control will reside on the ground until mission conditions dictate increased participation by the Space Station. If the Space Station is not present, the ground control facility will monitor platform operations on a periodic basis. In the case of tethered platforms, the procedure would be similar except that the role of checkout and verification could be assumed by the Space Station operating through the conductors in the tether.

3.1.1.3 Orbital Maneuvering Vehicle (OMV)

The concept for deployment and activation of an OMV is highly dependent on the OMV design. The OMV will be deliverable to orbit by a single STS launch. The OMV Attitude Control and Propulsive System would be serviced before STS launch. The OMV will share the Orbiter cargo bay with other payloads.

Orbital activation of the OMV will be accomplished by deployment of the OMV from the Orbiter using the Orbiter RMS and berthing to an assembly structure on the Space Station. The Space Station crew will then activate its systems, deploy required appendages, and perform system verification. Command and data links will be verified between the OMV and Space Station as well as with the ground.

After verification of proper system operations and the Shuttle's departure, the OMV will be released by the Space Station crew and free-flying tests performed to verify performance and operability.

When the OMV is active within the vicinity of the Space Station, the crew will be in control of the OMV maneuvers and system monitoring. When the OMV is not in use, it will be berthed to the Space Station in a powered down mode with any safety and critical systems being monitored by the crew of the Space Station. OMV consumable resupply will be delivered by the STS. OMV maintenance may require EVA by the Space Station crew.

3.1.2 System Management/Automation

Space Station platforms, OMV, and OTV will be designed for autonomous control to the subsystem level and below. Wherever practical, the ORUs will contain testing, checkout, and signal conditioning equipment that will simplify interfacing and subsystem data requirements. At the subsystem level, provisions will be made to provide redundancy management for the ORUs in that subsystem. This will include automatic failure detection, isolation, and reconfiguration. The subsystem level management function should not be shared between subsystems so that changes can be made economically on a subsystem basis. However, this management function should not preclude the sharing of redundancy and spares among subsystems where such sharing is feasible. The management function must provide sufficient interfaces with the data processing system to provide basic intended functions, trend data, evaluation, and manual override capability of the redundant management function.

Data on consumable quantities will be accurately generated at or below the subsystem level for transmission to a data and control area.

The data and control areas will have access to sufficient information on subsystems and consumables to generate the operations and configuration information required to plan and execute all Space Station functions.

During activation and checkout of the subsystems, most of the data will be monitored by ground operations. During this period, ground controllers will assist the flight crew with nominal and off-nominal procedures. As the systems are declared operational and the procedures mature, controlling tasks will be handed over from the ground to the Space Station.

The subsystem design shall incorporate the capability to operate in a manual, semi-automatic, or fully automated mode (i.e., progressive automation). This approach of progressive automation will allow for automation to be achieved in an orderly, phased manner. Operational and subsystem design shall provide a "user friendly" software interface to facilitate on-board operation/maintenance with a minimum of specialized training. Table 3-1 describes examples of "user friendly" software functions.

A test and control language shall be used for application software for ground/on-board integration, test, and operations. This test and control language and its implementation shall be user friendly to all customer and Space Station personnel throughout its life cycle and shall be capable of supporting progressive automation.

3.1.3 Activity Planning And Execution

Crew time will be allocated for the various required activities. Refer to Section 2.2.3 (t). The tasks that are considered under activity planning and execution include:

(a) Daily housekeeping chores and inventory management:

(1) Meal preparation;

(2) Personal hygiene;

(3) Repair parts used/remaining;

(4) Clothing used/remaining;

(5) Liquids, solids, gases used/remaining;

(6) Trash material accumulation; and

(7) Cleaning.

(b) Maintenance and repair schedules:

(1) Changeout of items at required maintenance intervals;

(2) Packaging of Earth-bound items for Shuttle return;

(3) Adjustments to operating payloads and Space Station instruments; and

(4) Equipment maintenance.

TABLE 3-1
EXAMPLES OF "USER FRIENDLY" SOFTWARE FUNCTIONS

- "PROMPTS" OPERATOR THROUGH AN OPERATION
- INFORMS OPERATOR OF ERRORS MADE AND WHERE
- PROVIDES A "HELP" FUNCTION TO ASSIST OPERATOR WHEN NECESSARY
- PROTECTS AGAINST SYSTEM CRASH THROUGH A DESIGN PROCESS CALLED "BULLET-PROOFING"
- INFORMS OPERATOR OF WHAT OPERATION IS TAKING PLACE (NEVER DISPLAYS A BLANK SCREEN)
- PRESENTS INFORMATION IN A COMPREHENSIBLE FORM (INCLUDING GRAPHICS WHERE APPROPRIATE)
- ALLOWS OPERATOR TO COMMUNICATE IN AN EASY, NATURAL WAY
- ADAPTS TO OPERATOR SKILL LEVELS

(c) Health maintenance:

(1) Recording of routinely checked biomedical parameters;

(2) Scheduling, implementation, and documentation of required exercise routines; and

(3) Recording of medications used/quantities remaining and/or treatments administered.

(d) Construction:

(1) Materials listing;

(2) Procedures for construction;

(3) Tools required;

(4) Time line of sequences;

(5) Workaround planning; and

(6) Training required.

(e) Satellite servicing:

(1) Rendezvous plans;

(2) Tools required;

(3) Material list;

(4) Procedures for servicing;

(5) Workaround planning;

(6) Time line of sequences; and

(7) Training required.

(f) Training activities:

(1) Training goals definition;

(2) Daily plans/schedules;

(3) Equipment lists;

(4) On-board/ground cassettes/films/training hardware;

(5) Records of training; and

(6) Training procedures development.

(g) Mission activities:

(1) Payload/manned laboratory activities;

(2) Data handling for payloads and Space Station;

(3) OTV/OMV activities; and

(4) EVA activities.

The orbital systems as well as the ground will provide trajectory/flight dynamics support for:

(a) System orbital maintenance;

(b) Orbit transfer flights;

(c) Satellite rendezvous;

(d) Orbiter rendezvous; and

(e) Mission planning activities.

Trajectory/flight dynamics support is part of crew schedule consideration since the computations determine when, how long, and at what attitude operations are performed.

There are two different methods of accomplishing activity planning and execution of the five major tasks. One method is on-board autonomy for daily scheduling of the ground-provided, long-range, scheduled tasks and functional objectives that have been detailed. The other is all activity planning on the ground. It is expected that a compromise between these extremes will be implemented and that a phased transfer of responsibility to the Station will subsequently occur.

3.1.3.1 On-Board Versus Ground Activity Planning

Autonomy is a valid design goal and envisions the crew having on-board software and display devices that accomplish flight activity planning. This method assumes a large decrease in ground support for activity planning. However, during current STS operations, flight planning "systems" have been built that assist in solving problems of crew activities. These "systems" may continue to be used during the initial flights and will accomplish the initial assembly and activation of the Space Station System. Ground-developed systems for crew activity planning also may be used, or new systems developed, to accommodate long-range planning for System operations. Where the information resides is not important as long as access by orbital crew and the ground is relatively simple, although some duplication of Space Station data may be required for contingency operations.

3.1.3.2 Flight Activity Operational Scenario

The Space Station crew should have a daily activity plan available for input to and review upon completion of their sleep period. Since the crew size could eventually be in excess of 10, sufficient display devices of the approved plan should be available for effective on-board coordination. The ground may be called upon to clarify or amplify portions of the plan as required. As the daily plan is accomplished by the crew members, a record/entry is made into the activity-planning computer support system. The data will then be used to aid the crew members and/or the the ground in short and long-range future planning, respectively. On-board crew display systems for activity planning should allow the crew to make adjustments to the plan to reflect their changing needs and to register their accomplishments.

3.1.4 Safety And Emergency Planning

The design of various elements of the Space Station must allow operations that do not introduce unacceptable risks to the crew or equipment, and provide the capability for onboard repair and reactivation of systems damaged by foreseeable catastrophic events such as fire, meteoroid impact, or vehicle collision. A safe haven/retreat capability, and the ability to rescue the crew after unforeseen events or multiple events that render unassisted repair and reactivation impossible, must be provided.

Safe operations of the Space Station elements will be achieved by imposing requirements on system design and by proper procedures and training for the flight crews. Crews will be trained prior to flight on how to operate the systems safely and how to handle potentially hazardous elements such as OTVs, OMVs, and MMUs. Refresher training for hazardous operations will be provided to the flight crew on-board the Space Station.

Crews must be capable of handling various types of emergency situations during manned operations of the Space Station. Emergency training and backup systems will be provided for:

(a) Fires, including housekeeping and operational techniques to minimize the potential for the occurrence of a fire;

(b) Sudden loss of cabin pressure;

(c) Injuries/medical emergency;

(d) Loss of power/thermal control;

(e) Radiation;

(f) Atmosphere contamination;

(g) Damage to external equipment/systems;

(h) Tumbling/loss of control;

(i) Explosion;

(j) Abandonment of Space Station;

(k) Depletion of consumables;

(l) Loss of access to any hatch;

(m) Low/high oxygen concentration;

(n) Emergency collision avoidance tactics; and

(o) Fluids/gases leakage.

Those appendages external to the Space Station elements that are vulnerable to damage will either be capable of being jettisoned or being removed by other means.

Crew proficiency in responding to emergency situations will be maintained by the use of unscheduled, simulated, on-board emergency reaction exercises.

3.1.5 Logistics

Logistics for the orbital operation of the Space Station system will consist of the orderly planning and execution for the resupply of consumables, delivery of spare/repair parts, on-board equipment repair, propellant resupply, delivery or return of payloads or the delivery or return of any new or damaged element, return of waste, return of processed materials, Space Station growth and crew rotation.

Long-term activity planning will provide the integration of requirements and schedules for the various logistics tasks. The STS will provide the means for the delivery to the Space Station or the return to the ground.

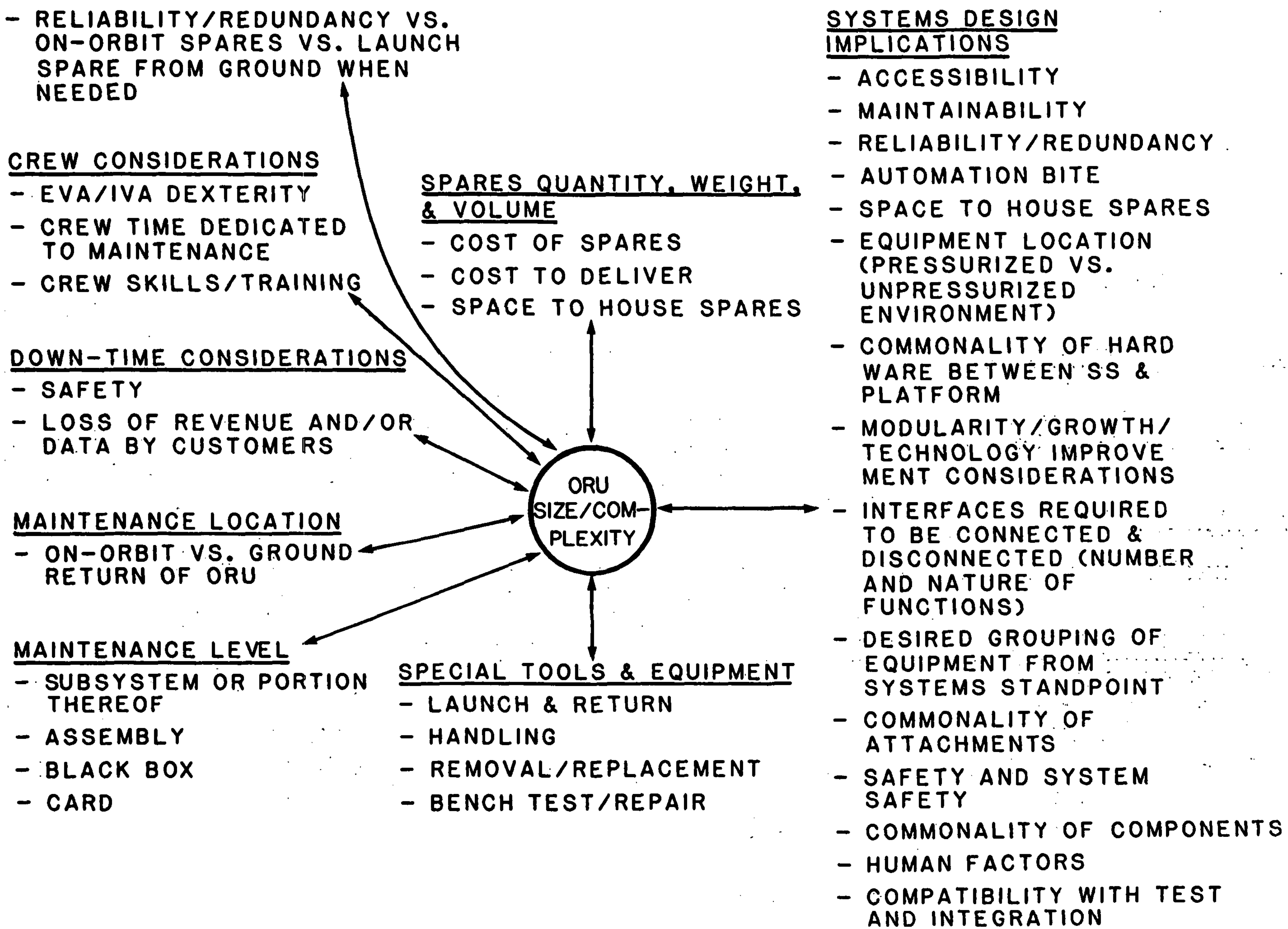
In order to minimize the logistics tasks, consideration should be given, as an example, to the level of system redundancy of Space Station elements, quantities of consumables on-board, and reliability/maintainability requirements to reduce the frequency of required resupply or repair missions.

3.1.6 Maintenance Of Systems

Provisions will be made to easily plan, inspect, verify, and implement replacement and/or repair of equipment associated with the platforms, Space Station, MMU, OMV, OTV, etc. This capability is required at the lowest practical level. However, maintenance may not be limited to the ORU remove and replace level, but may encompass repairs to structural, fluid, mechanical and electrical systems/subsystems. An on-board workshop/tools may be used to effect these types of repairs. Figure 3-1 lists some of the considerations that must be addressed in each case to determine the maintenance philosophy for a system/ subsystem failure.

(a) On-board automated systems will be provided for checkout, monitoring, warning, fault isolation, and fault recovery to a level consistent with safety and with the in-orbit maintenance and repair approach selected. Emergency control and repair of a failure or damage also will be provided. Repair modes will be selected that have minimal effects on Space Station operations and will, in no case, reduce the operation of critical systems below the fail safe level.

FIGURE 3-1
RELIABILITY/MAINTENANCE TRADES



(b) Individual subsystems in the Space Station System will provide for fault isolation and subsystem checkout. On-board checkout will be automated, and fault isolation and subsystem checkout will be performed in flight.

(c) Subsystem design will include a built-in-test (BIT) capability to facilitate detection and reporting of functional discrepancies. As a minimum, this BIT capability will enable failure detection at a functional path level in-flight along with fault isolation. BIT will be implemented by utilizing periodic or continuous monitoring by built-in-test equipment (BITE) and self-test circuitry and by providing adequate test point information at the electrical interfaces. BITE will be provided for all time-critical equipment.

(d) Subsystems equipment will be removable or replaceable by use of installation-handling devices and an on-board set of standardized tools. The interconnecting plumbing and wire runs will have suitable attachment, length, and mounting characteristics to facilitate removal/replacement.

(e) These subsystems will be further subdivided into submodule units that can be isolated and replaced at the ORU level. Some ORUs may be repaired at the workbench level of maintenance and reinstalled depending on the established maintenance concept.

(f) Trend analysis data for failure prediction will be provided through the data management system for transmission to the ground. Advisory information will be provided to the crew for possible unscheduled maintenance.

(g) Critical systems will be capable of undergoing maintenance without the interruption of critical services and will be "fail safe" while being maintained. Certain important non-critical systems will be designed to be single-fault tolerant so that maintenance and repair can be scheduled within the constraints of other high priority crew activities.

(h) As a goal, all failures or damage (including structural) will be repairable. Failure or damage events with an expected occurrence rate less than 10^{-2} per year will be considered "exceptional" and may employ exceptional repair measures such as temporary interruption of normal Space Station System operations or temporary depressurizing deactivation of a module. The aggregate expectation of any exceptional repair or maintenance activity due to all causes will be less than 10^{-1} per year.

(i) If practical, all limited-life components and subsystems will be designed to allow ground and on-orbit inspection/monitoring for determination of remaining useful life.

(j) Loss of redundancy for critical functions will be detectable automatically through a standard workstation and the crew alerted through caution and warning system signals.

(k) The design requirement is to provide a selected set of on-board spares and hardware/software maintenance capability for subsystems expected to experience occasional failures or needing refurbishment and maintenance.

(l) Overall Space Station System operations will not be degraded during normal maintenance, checkout, and testing.

(m) All systems will be capable of on-orbit fault isolation at a minimum to the ORU level without disconnections or use of carry-on equipment.

(n) Redundant functional paths and subsystems will be designed so that their status can be verified without removal of ORUs.

(o) ORUs may be further subdivided into modular units that can be isolated and repaired/replaced at the workbench level of maintenance with general purpose test equipment.

(p) Space Station System subsystems will be designed so that any single credible failure will result in a safe condition. Subsequent crew action may be required to restore normal operations.

(q) System design will provide periodic or on-demand system checkout to allow early detection and maintenance of faulty equipment and avoid inconvenient interruptions in service. System design will also provide automatic fault detection. Subsystem equipment will have self-test and performance-monitoring capability as required to assist in system-level checkout and fault detection and isolation.

(r) Replacement of subsystem equipment will not require the removal or disconnection of other subsystem equipment, nor will replacement of equipment require the removal or disconnection of other equipment. For example, electrical breakers and fluid valves will be so located that the removal/replacement of ORU's will not necessitate bringing down primary electrical or fluid systems.

(s) System design will provide interfaces that prevent mislocation of equipment or intermixing of equipment interface connectors.

(t) Removal of ORUs for maintenance action will not introduce a hazardous condition.

(u) Adequate clearance will be provided during service and maintenance activities to prevent interference with other Space Station System operations and avoid creating a safety hazard.

(v) A maintenance workstation will be provided within the confines of the Space Station. Growth capability of the workstation will permit the inclusion of a machine shop, including equipment for metal working, welding, braising, cutting, etc. A comprehensive set of test equipment and tools, capable of usage at the designated maintenance workstation or at the worksite (either EV or IV), will be provided for maintenance operations.

(w) The Space Station design will include controlled storage facilities for storing usable spares and test equipment and will provide for segregation of discrepant equipment pending disposition.

The Space Station System will include a closed-loop system for the reporting of all problems (failures and unsatisfactory condition reports) and will establish corrective action for all problems concerning flight, test, simulator, and training hardware where that hardware is representative of flight hardware, GSE, applicable GFE, and spare hardware. Analysis of problems reported shall be performed to determine the cause and to implement adequate measures to prevent recurrence.

3.1.7 System Upgrading

The Space Station System operational lifetime will be from 10 years to indefinite. This lifetime will be achieved by periodic maintenance and repair of lifetime-limited components in the various systems.

The Space Station System will provide incremental development and buildup so that mission requirements can be met on a time-phased basis. As the demand for additional, space-based services increases or mission objectives change, the System capabilities will be phased to match these demands.

The long lifetime of the Space Station System will allow the opportunity to upgrade systems. As new technologies are developed or new capabilities become available, the modular design approach for the elements of the Space Station System will permit their incorporation.

3.1.8 Configuration Control

The Space Station System will change during its operational lifetime as described above. As a result of the various changes that each element will experience, it will be necessary to provide a configuration control system that will track and maintain the current configuration of each element's hardware, software, electrical, structural, fluid, and mechanical subsystems. This system will be accessible to both the orbital crew and ground personnel for data input and retrieval. The current configuration data should also be a part of the Space Station System data base.

3.1.9 Extravehicular Activity

Definitions. EVA is used to describe activities performed by the crew member in a vacuum or unpressurized environment. IVA includes those that occur in a shirt-sleeve environment.

Programmatic Requirements For EVA. Program and mission objectives define a need to provide a base for assembly, construction, service, and recovery of increasingly large and complex payloads in Earth orbit. Inherent to this support function is the task of doing real work in space, much of it utilizing an operational EVA capability. For example, assembly of large space structures and satellite retrieval and servicing tasks will be accomplished by the flight crew using EVA and/or by the use of attached or detached remote manipulators and/or other assembly facilities. Additionally, EVA may be a mode of operations for vehicle maintenance exterior to the crew module and OMV and OTV servicing/maintenance operations. A goal is to evolve the Station to replace EVA functions with teleoperation and robotics.

Operational Requirements. The Space Station EVA capability will be supported by a complement of specialized EVA equipment and the design features of the Space Station itself.

The extravehicular mobility unit (EMU) is an independent, anthropomorphic system that provides environmental protection, mobility, life support, and communications for the Space Station crew to perform EVA in Earth orbit. The EMU will consist of a space suit assembly that includes the basic pressure garment components, a primary life support system, a backup life support system for emergency use, a radio communication system, and the displays and controls required to operate them.

The Space Station/EMU interface design is critical to eliminate cumbersome and time-consuming pre-breathe requirements and to provide quick access and multiple EVA capability. A regenerative EMU life support capability is essential to eliminate the parasitic need for expendables to support EVA. The EMU caution and warning system will monitor system configuration and environmental parameters, and will provide status of consumables making the EMU independent of ground monitoring and control. The EMU will emphasize:

(1) Improved reliability with minimum maintenance and pre-EVA checkout requirements;

(2) Increased comfort and improved crew-machine interfaces to support 8-hour EVAs; and

(3) Reduction of pre-breathing requirements.

Customized suit fitting requirements will be reduced through use of standard-sized components that combine with interchangeable sizing elements to fit a wide range of male and female crew. Flight suits will be carefully sized to match the EVA crew members. Sufficient EMUs will be included in the baseline mainifest to support the described EVA rate and simultaneous EVA capability. Suit turnaround constraints (e.g., suit drying and sizing) will be minimized. Several items of ancillary equipment, such as tethers, mini-work stations, helmet-mounted lights, and helmet-mounted television, complement the pressure-suited crew member's capabilities.

The airlock provides the means for the suited crew member to transfer from the Space Station to space without having to depressurize the entire crew compartment. The Space Station will provide EVA airlocks with the capability for a variable controlled rate of depressurization to accommodate nominal and emergency operations. Depressurization control will be possible from inside and outside the Space Station and from inside the airlock. A pumping capability and storage reservoir will minimize the loss of airlock expendables and provide the capability of using the airlock as a hyperbaric chamber. The capability of operating the airlock without the pumping system will provide redundancy and emergency EVA/IVA operations. Additionally, the airlock will provide stowage of the EMUs and will provide the interfaces and associated displays and controls for the Space Station systems that support EMU operations and servicing. Provisions for EVA preparation, EVA equipment storage, recharges, checkout, maintenance, and post-EVA activities will be made in the airlock. Each airlock, in addition to the storage and system accommodations, will be large enough to support the pre- and post-EVA activities for two crew members at a time. The airlocks will be located to be within the reach envelope of system manipulators to be used in a cherrypicker mode. A window will be placed close to the airlocks to allow an IVA crew member to have visual contact with the EVA astronaut immediately after he has left the airlock.

Handholds, handrails, and restraint attach points will be provided along all EVA routes and at each EVA hatch. These will be compatible with use by teleoperated or robotics machines. Tether management slidewires will be provided to support operational safety requirements without interference to on-orbit operational envelopes. Sufficient floodlights will be provided to aid EVA crew visibility during all operations. Closed-circuit television (CCTV) cameras external to the Space Station will provide a means for the crew member to perform limited pre-EVA inspections of the task areas and allow the OMV crew members to verify EVA task requirements, accuracy of techniques applied, and satisfactory task completion. The OMV cameras and the Space Station-based RMS cameras may provide additional viewing. External stowage boxes with integral handrails and foot restraints will provide for stowage of EVA tools and support equipment. The stowage boxes will be modularized with easy attach/detach capability for transport and worksite convenience.

Various types of EVA equipment will be included in the Space Station baseline configuration to provide the full range of EVA capabilities necessary to accomplish construction/satellite servicing and Space Station repair. These equipment types include portable foot restraints, manipulator foot restraints, and a full complement of specialized EVA tools. Helmet-mounted cameras will be provided for EVA operations to assist in the performance of duties.

3.1.10 Data Base, Ground, And Flight

A major new function related to long-duration flight operations of the Space Station System is the information storage and retrieval system or data base and support the Space Station Systems and subsystems. This on-line, real-time data base will be user friendly and must provide the storage and retrieval capability for functions such as crew procedures, vehicle procedures, library, data archives, mission planning, crew planning, remaining limited life (time/cycle) information, inventory/logistics, logistics maintenance-related activities, medical records, mail, crew entertainment and expert systems support. The performance of this data base should be sufficient to meet the operational needs of on-board software and automated crew checkout procedures.

A functional single data base with backup capability will be developed for on-board or ground use. The decision as to the software split between on-board and ground will be based on development cost and the autonomy philosophy, although some duplication of Space Station data may be required for contingency operations.

The data base system design should not preclude the Space Station crew from real-time interaction with the data base through air-to-ground communications if the software resides on the ground.

3.1.11 Medical Operations

Health maintenance operations encompass all activities of the flight crew because everything they do has some potential impact on their health and well-being. A generalized requirement will be developed for assuring that the crew will be free of communicable diseases, etc., prior to flight commitment. An important medical operations consideration is the evolutionary buildup that the Space Station will go through.

During the initial manned missions of the Space Station when safety considerations dictate that the Shuttle Orbiter be docked to the Space Station, it is anticipated that the Shuttle Orbiter medical system and the associated operational procedures will suffice.

As the Space Station evolves to a configuration that permits manned operations without the Shuttle Orbiter present, a capability must be provided on-board the Space Station for health care. A health maintenance facility will provide, to the extent possible, for health maintenance, extended medical care, and stabilization and transport of one or more ill/injured crew members.

The diagnostic equipment and procedures required for medical care will probably be more frequently employed in health maintenance and physiological status monitoring. Rapid advancements in medical technology will likely provide the necessary capabilities in small, sensitive, low-power, simple-to-operate devices. Moreover, many devices may be amenable to integration (e.g., electrophysiological monitors such as EKG, EEG, EOG, and EMG). On-board computers will handle multiple inputs.

From a medical operations standpoint, some health maintenance and physiological monitoring tests should be performed frequently during the first weeks at null-gravity and less frequently thereafter, up until the week or two before return. The physiological state of the crew will be monitored carefully before subjecting them to the stresses of entry and return to low-g. It may be necessary to provide countermeasures (e.g., anti-g suit, lower body negative pressure, and fluid ingestion) depending upon status.

To handle physiological status monitoring and any medical care activities, it is desirable to have a physician/surgeon on-board. Such a crew member would be cross-trained to perform other duties such as the monitoring of environmental control systems and the nutrition and hydration status of the crew. A scientifically-trained physician would also be expected to be involved in other science and applications missions. Moreover, the presence of a physician/surgeon on-board a Space Station system that lacks rapid return capability may provide some psychological security to the crew.

In addition to the prime medical-care specialist, whether a physician/surgeon or a highly trained crew member, another crew member must have extensive emergency medical training.

The experience gained during the initial manned operations will likely impact the anticipated requirements for operation in the future growth phases. For example, continued physiological monitoring is anticipated, but it may be desirable that the required diagnostic equipment be upgraded to the then current state-of-the-art. During the growth phases of operations, increased hazards from EVA (construction, OTV, and free flyer servicing) are possible. Medical care facilities for trauma above and beyond that needed for earlier operations are likely.

3.1.12 Habitability Considerations

Habitability is a discipline (like safety or reliability) that contributes to the well-being, morale, and health of the crew. It is a discipline concerned with comfort, ease-of-use, avoidance of nuisances, and other human factors, and not with basic survival. A Space Station module that supports mixed crews living and working for 90 to 180 days must have good habitability to maintain morale and productivity. Table 3-2 lists specific areas where habitability requirements should be applied. Suggested design guidelines for the elements presented in Table 3-2 are presented in the following sections. Sizing should be comfortable for the 25th to 75th percentile male and female.

3.1.12.1 Internal Environment

(a) Respirable Atmosphere. The ECLSS will provide adequate, breathable atmosphere to maintain the health, well-being, and comfort of the crew within all pressurized, habitable portions of the Space Station.

(b) Lighting. The Space Station will provide adequate lighting levels and sunlight control in each habitable portion of the Space Station. The lighting system will be such that adequate light is available for all tasks, as well as for living within the Space Station. Particular care will be maintained to prevent shadowing, high contrast, glare, and light shining directly into the eyes of a crew person during the performance of tasks as well as during general movement about the Space Station.

(c) Acoustics. The Space Station will provide sufficient sound control to reduce all Station-produced noises to the minimum level reasonable achievable. Crews must be able to converse without shouting and must be able to hear the various caution/warning systems and communication systems without specialized hearing aids or locations. The noise level in the sleeping quarters requires special consideration.

TABLE 3-2
HABITABILITY CONSIDERATIONS

INTERNAL ENVIRONMENT
- TEMPERATURE AND HUMIDITY
- ATMOSPHERIC COMPOSITION, MOVEMENT, AND REVITALIZATION
- ACOUSTIC AND LIGHT LEVELS
- VIBRATION

ARCHITECTURE
- VOLUME AND GEOMETRY OF COMPARTMENTS
- ACCESS AND EGRESS
- COLORS AND TEXTURES
- STOWAGE AND RETRIEVAL
- PRIVACY
- TRAFFIC PATTERNS
- SEPARATION OF LIVING/RELAXING AREAS FROM WORK AREAS

MOBILITY AND RESTRAINT
- LOCOMOTION RESTRAINT AIDS
- MECHANICAL ASSISTANCE
- ACCESS

FOOD
- NUTRITION
- PALATABILITY
- MEAL PREPARATION, SERVING, CONSUMPTION, AND CLEAN-UP

CLOTHING
- DUTY/OFF-DUTY
- SLEEPWEAR

CLOTHING (Continued)
- PROTECTIVE
- CLOTHES WASHING/RESUPPLY
- ADJUSTMENTS FOR CHANGED BODY CONFIGURATIONS

PERSONAL HYGIENE
- BATHING/GROOMING
- BODY WASTE ELIMINATION

HOUSEKEEPING
- CLEANING EQUIPMENT, PROCEDURES, AND SCHEDULES
- REFUSE COLLECTION AND DISPOSAL
- INTERNAL REFURBISHMENT OF SPACE STATION

COMMUNICATIONS
- INTRAVEHICULAR (WITHIN FLIGHT CREW)
- OUTSIDE (FAMILY, FRIENDS, AND GROUND CONTROL)

CREW ACTIVITIES
- WORK/REST SCHEDULES
- OFF-DUTY ACTIVITIES

PSYCHOLOGICAL FACTORS
- CREW NUMBER AND MIX
- COMMAND STRUCTURE/AUTHORITY SCHEME
- TRAINING

3.1.12.2 Habitat Interior Design

(a) The geometric arrangement of compartments will provide necessary access and egress to all functions within the Space Station. A low-g orientation (local vertical) shall be provided. Traffic patterns shall be considered of prime importance. Separation of private or rest areas from noise-producing work areas shall be a high-priority consideration. Multiple use of volume is extremely important. A wardroom shall provide sufficient space to permit a standard Space Station crew to dine together. The wardroom shall provide a lounging area between meal times.

(b) Interior appointments, including decoration and arrangement of furnishings, will be in accordance with good architectural and interior design practices; e.g., providing visual space and stimulation. The intent is to provide crews with soothing, restful surroundings. Provisions for rearranging decor should be considered.

(c) Stowage and retrieval considerations of all required crew support items, as well as Space Station System equipment/spares, will be a major factor in the interior arrangement of the Space Station. The various stowage items shall be located as close to their use location as is practical. The problems of restowing items shall be considered when determining required stowage volumes. Color graphics shall be utilized as an aide in crew location of stowage items. Modular stowage lockers shall be incorporated into the overall interior arrangement of the habitat. Common latching devices shall be used throughout.

(d) Color and texture within the habitat shall be selected to provide visual orientation cues (local vertical), equipment stowage location cues, use location aids, aesthetic variety, and contrast for the crews. Good interior decorator practice shall be considered as imperative in this area.

(e) Private sleeping quarters shall be provided for each crew member during standard operational phases of the Station's mission lifetime. Sleeping quarters shall provide the crew with stowage facilities for clothing and personal items, music, recreational items, desk facilities, and a means of securing clothing removed for the sleep period. Sleeping quarters shall be quiet. Sleeping quarters shall provide ample room for changing clothes. Consideration should be given to private quarters viewing ports.

(f) Observation windows will be required for work-related viewing. They also will be a prime source of recreation. Therefore, provision of the opportunity to rotate around the viewing ports to allow body orientation to the Earth as appearing "down" should be considered.

3.1.12.3 Mobility and Restraint

The Space Station System will provide crew and equipment with sufficient restraints and locomotion aids to enable crews to function efficiently and effectively. Hatches or doors, internal to a single module, should be configured to allow pass-through without body reorientation (crew person remains vertical).

(a) Locomotion. Handholds and pushoffs will be incorporated into the interior arrangement of the module to provide crew persons the ability to push themselves to any area and to be able to halt their movement at any location. Equipment design must take into account that any surface or protrusion could be used as a locomotion aid.

(b) Restraint Aids. Properly designed and developed foot restraints generally are adequate to provide crew persons with sufficient restraint. The foot restraint must be positive, passive, easily engaged and disengaged, lightweight, and snug-fitting. For tasks that require extreme steadiness, additional body restraints may be required.

(c) Equipment Restraints. Restraints will be provided to anchor every item of use that is not permanently attached to the Space Station. Items such as velcro patches, bungee cords, magnetic attachments, and the like are to be considered and used as restraints. Additional restraint concepts (for example, airflow tables) should also be considered.

3.1.12.4 Food and Drink

The Space Station will provide a galley system to provide the requisite food and drink for the crew.

(a) Varied and complete meals will be furnished for the crews. In addition, snack items will be provided. The food shall consist of items that are hot, cold, and at room temperature. Meals shall be nutritionally balanced and palatable to the crews. Condiments shall be provided for variety. Bulk storage and preparation shall be considered.

(b) Varied types of drinks, hot, cold, and room temperature, will be provided.

(c) The galley will provide for meal preparation (heating cooling, and serving). Stowage of all utensils, food, condiments, and accoutrements necessary for food preparation and eating shall be included. The galley also shall provide for cleanup and for trash management of the food system.

(d) Sufficient volume for dining should be initially allotted to seat and feed the entire crew at each meal. Crews should initially be able to dine together as a group. This volume can be used as a wardroom/lounge between meals. As the Space Station crew size increases, additional dining areas will have to be provided for and/or crew dining times will have to be varied in order to accommodate everyone.

3.1.12.5 Clothing

The Space Station will provide crews with adequate clothing and the cleaning/washing facilities to maintain that clothing.

(a) Duty Garments. Clothing worn during the scheduled activities for the crew includes under and outer garments. The clothing shall provide the wearer with adequate pockets, etc., to serve as small equipment restraints. Flammability, cleanability, and wear resistance shall be considered. The change in body size in microgravity should be considered. Clothing will be designed for easy donning /doffing.

(b) Off-Duty Garments. The clothing worn during exercise and/or casual rest periods may include portions of the duty garments. Off-duty clothing should provide variety and visual stimulation for the wearers.

(c) Sleep Garments. Sleepwear shall be provided for the crews.

(d) Special Clothing. Any protective clothing or garments deemed necessary for the health, hazard protection, and well-being of the crews for particular missions shall be furnished.

3.1.12.6 Personal Hygiene

The habitat shall provide facilities for body waste collection/disposal and personal cleanliness and bathing. These systems shall be private and easy to use, to maintain, and, especially, to clean.

(a) Body Waste Collection. A means of collecting fecal matter, urine, and vomitus from the crew persons and of disposing of that material shall be provided. Facilities shall be private, easy and efficient to operate, and sized for the 5th to 95th percentile male and female.

(b) Personal Cleanliness. Facilities shall be provided to aid the crews in keeping hair, face, hands, and teeth clean and healthy. Shaving facilities will be provided.

(c) Bathing. A full body shower facility will be provided. This facility also may be used in case of chemical burns. This facility also may be used in case of body contact with toxic chemicals.

3.1.12.7 Housekeeping

The habitat shall be designed and arranged to facilitate cleaning. The equipment necessary to maintain this cleanliness shall be available to the crews. A centralized wet/dry vacuum system should be considered.

All trash generated by the crews in using the various systems of the Space Station shall be collected and disposed of. Collection points shall be readily accessible and located near the areas of greatest trash generation. Trash shall be compacted and treated with bactericides to prevent gases or odors. It shall be stored and returned to Earth.

3.1.12.8 Communications

Person-to-person communication within the habitat, between the habitat and the ground, and between man and machines will be provided.

(a) IVA Communication. The Space Station shall provide means to communicate readily from any point in the habitat to any other point. Noise levels shall be sufficient low to allow unamplified conversations. The IVA communication net shall be designed and located to prevent feedback and speaker interference.

(b) Person-to-Ground Communication. Facilities shall be provided to enable any crew person to talk privately with his family/friends on the ground. This will include radio communications and may include live, two-way TV viewing. The capability for private medical conferences will also be provided.

(c) Crew Displays and Controls. All displays and controls provided for crew use shall incorporate design practices for good human factors. Any dedicated switches or circuit breakers shall be protected against inadvertent operation. Multiple use displays shall be used wherever practical.

3.1.12.9 Crew Activity

Work/rest/leisure schedules shall be developed to effectively utilize the crew's time and capabilities and maintain its productivity. Equipment necessary to accomplish this shall be provided.

(a) Off-duty activities shall include leisure and entertainment functions. Equipment, lounge areas, snack foods and drinks, and time shall be provided to enable the crews to refresh themselves during off-duty hours. These will include group functions as well as private leisure.

(b) The schedules shall include sufficient sleeping time for the crews. Private sleeping quarters shall provide controlled sound and light levels. Necessary sleeping bags or liners shall be provided.

(c) Exercise equipment and techniques shall be provided to enable crews to retain the requisite physical body tone. Such equipment/ techniques can be used for recreation also. Each crew person may require one or more hours/day of exercise and simultaneous reading, TV viewing, or music listening.

3.1.12.10 Psychological Factors

Psychological factors that may affect Space Station habitability and crew productivity are: (1) The number and mix of the crew; (2) the command structure/authority of the crew; and (3) the small group dynamics training provided to the crew and their families prior to their stay on the Space Station.

(a) Particular attention will have to be given to the number of crew members occupying the Space Station and to the crew mix (male-female ratio). These variables can affect crew productivity and Space Station habitability. Odd-numbered crews (5 or more) are probably optimum to prevent the formation of opposing groups within the crew structure and to establish more effectively a command authority scheme. The male-female ratio of the crew and other factors such as marital status will also have to be optimized.

(b) A command structure/authority scheme for the crew will have to be established before flight. The crew members should participate in the development of any command structure/authority scheme.

(c) Small group dymnamics training, such as group dynamic training, should be provided to all crew members and their families before flight. This training will be required to make each crew member aware of and conditioned to the psychological phenomena and factors that may affect his/her stay on the Space Station.

3.1.13 Navigation

There will be an orbit navigation system whose functions will be to:

(a) Maintain knowledge of the Space Station orbit.

(b) Maintain the orbit in the presence of atmospheric and other disturbances.

(c) Provide state and celestial geometry data to onboard customers, applicable to any specified time, past, present, or future.

The Space Station orbit may be corrected either by discrete reboost velocity increments or by continuous modulation of an onboard thruster. Continuous correction would offer the advantage of effectively nulling the net contact acceleration, thus continuously approximating a true zero-g environment. No discrete reboost correction should be imparted without prior notification and authorization from the onboard crew, if any, or ground operator.

The orbit navigation system shall be automated to the maximum practical extent in order to minimize demands for time from onboard and ground crews.

3.2 NEW ELEMENT OPERATIONS

After the initial Space Station System configuration has been in operation for some time, it will be desired to continue its growth. This growth may consist of additional elements that will be attached to the Space Station to provide more redundancy and more space for larger crews, assembly aids, shelters, or laboratories. As new technologies or capabilities become available, they can be incorporated into the Space Station System.

Each of these new elements will be delivered to the Space Station by the STS and attached using the remote manipulator. Activation and verification of the new elements will be performed by the Space Station crew. Systems will be monitored in parallel by the ground until confidence in the operation of the new elements is achieved.

3.3 RETURNABLE ELEMENT OPERATIONS

Throughout the operational lifetime of the Space Station System, the STS Orbiter will provide the means for transporting items to and from the Space Station System on a routine, periodic basis. There are two types of elements that the STS Orbiter will transfer frequently, the resupply modules and the payloads.

A full resupply module will be attached to the Space Station by a system such as the Orbiter RMS, and the depleted resupply module will be removed and returned to the ground by the Orbiter for resupply. The depleted module may contain waste and other materials requiring transfer to the ground.

The payloads may either be placed inside the Space Station or attached to an external port by the remote manipulator system. These payloads will also be transported to platforms by either the Orbiter or OMV. Some payloads will be attached to the OTV for transfer to other orbits. Payloads will be retrieved by the OTV, OMV, or Orbiter for return to the ground if required.

Even though it is not planned as a normal operation, some elements of the Space Station System may be capable of being deactivated and returned to the ground by the Orbiter for major repair if required.

3.4 SHUTTLE OPERATIONS

The STS will be interactive with the Space Station System during rendezvous/docking, berthing, resupply of consumables, propellant transfer, crew rotation, and delivery and return of mission equipment including satellites. Operation of the Orbiter on and around the Space Station requires special safety considerations.

3.4.1 Resupply

When performing a resupply function, the Orbiter will be required to freight a cargo canister, called a resupply module, which may contain Space Station propellants, water, food, clothing, and replacement ORUs. Resupply of cryogenic H_2 and O_2 for high energy OTVs and fuel modules and material replacements for platforms is also required. However, platforms may be resupplied by returning the platform to the Space Station by use of the OMV, reeled in if tethered, or rendezvous.

During STS proximity operations with the Space Station, the STS will have control authority subject to Space Station proximity control considerations. Station and STS ground control will provide support as required.

Orbiter interaction with the Space Station during berthing/docking operations requires that the Space Station not be translated and that the Orbiter perform all translation maneuvers. Docking and undocking maneuvers will be planned to minimize Reaction Control System (RCS) plume impingement and will minimize affects on Space Station ACS. Once docked, the resupply module will be removed from the payload bay using the Orbiter RMS and then berthed to the Space Station. Space Station ACS constants will be changed to accommodate the additional mass. Docking targets, alignment devices, and lighting will be provided by the Space Station; docking indications of capture and hard docking will be provided to both flight crew and ground. Long-term, docked, Orbiter-tended operation with the Space Station requires that the Orbiter be reconfigured to an appropriate quiescent operation mode.

Resupply of platforms, such as an Earth astronomical observatory or a materials processing platform with fuel pods, replacement ORUs, cryogenics, or new processing materials, will require most of the same operational considerations that are listed for the Space Station. The same will be true for resupply of the OMV. Fuel replenishment of a Space Station will require low- or zero-gravity fuel transfer techniques or exchange of fuel tanks.

3.4.2 Delivery, Stowage, and Return of Mission Equipment

Mission equipment such as a resupply module, OTV, OMV, processed material canisters, retrieved satellites, or a Space Station module requires proper interfaces with regard to manipulation and payload bay stowage.

3.4.3 Safety

Safety is a major consideration when the Orbiter is executing approach and docking with any orbital module, berthing resupply modules, transferring fuel, and in system configuration during extended, Orbiter-docked operations.

Generally, docking/berthing safety and success will depend on standardization of proximity operation crew procedures, docking aids such as targets, alignment devices, and adequate lighting, as well as docking indications to the flight and ground crew of capture and hard dock.

Orbiter systems during extended docking operations will be configured for powered-down, quiescent operations. Orbiter caution and warning capability, as required, will be provided to the Space Station or monitored by the ground when the Orbiter is unoccupied. However, Orbiter systems will remain configured to permit an emergency egress/undocking at any time.

On-orbit fuel storage, which may consist of both cryogenic oxygen and hydrogen for high energy OTVs as well as storable fuel for Space Station, OMV, and payload attitude control, presents a potential hazard that must be minimized through design.

3.4.4 Fuel Scavenging, Transfer, and Storage

Scavenging of cryogenic H_2 and O_2 and storable propellant from the Orbiter and ET is an option as a source of propellant resupply for the Space Station System. However, the techniques and hardware required for scavenging, transfer, and storage remain to be developed. The Shuttle System interaction with the Space Station System is limited to the propellant transfer.

3.5 SPACE STATION/OMV INTERACTION SCENARIO

The OMV for Space Station System operations will use an advanced space-based OMV concept derived from the Shuttle-configured baseline. The baseline configuration is of modular construction and is sized to fit into and operate from the Shuttle payload bay.

Figure 3-2 illustrates an example OMV concept. The center section is the propellant module containing the main engine and four fuel tanks. The side sections contain the RCS thrusters and four helium tanks. The top and bottom sections contain the avionics for guidance, navigation, and control.

A cold gas RCS may be required, in addition to the propulsive RCS, for space-based OMV for operations in the vicinity of the Space Station. Solar arrays may also be added to the space-based OMV to supplement battery power.

Table 3-3 is a summary of OMV turnaround requirements in terms of overall Space Station System operations and associated interfaces.

FIGURE 3-2
OMV CONCEPT EXAMPLE

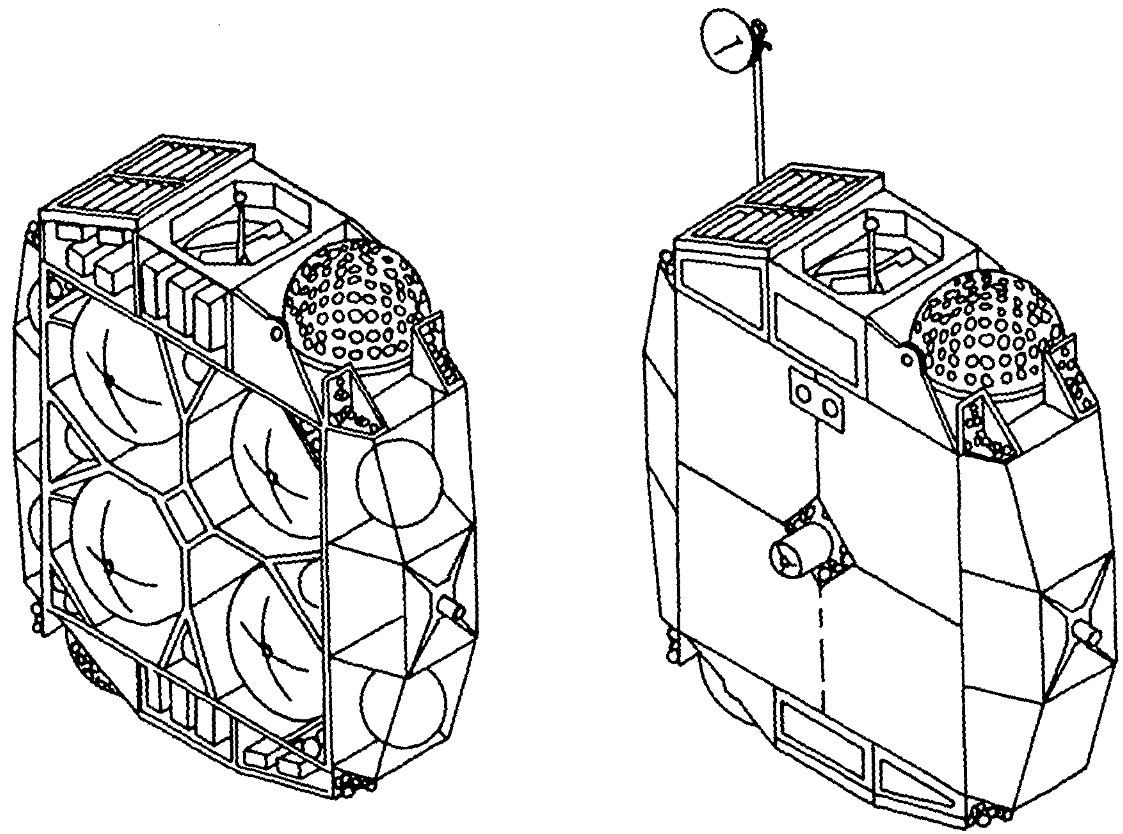


TABLE 3-3
OMV TURNAROUND REQUIREMENTS

SSS OPERATIONS	INTERFACE
– CHECKOUT	– C/O EQUIPMENT & HARDWARE CONNECTIONS
– LAUNCH	– CONTROL EQUIPMENT & HARDWARE CONNECTIONS
– CONTROL	– RF LINK (VIDEO & DATA)
– MONITOR	– RF LINK (DATA)
– BERTHING	– BERTHING ATTACHMENT
	– SS MANIPULATOR
– SERVICE (RECHARGE BATTERIES)	– POWER (500 WARRS)
– RESUPPLY (FUELING)	– FUEL SUPPLY (REPLACEMENT PROPELLANT MODULE/CHANGEOUT OMV)
– ROUTINE MAINTENANCE	– SPARES MODULES/PARTS
	– TOOLS
	– TEST EQUIPMENT
	– STORAGE & MAINTENANCE FACILITY

Servicing requirements would include system checkout and battery recharging. It is assumed that the RF control and monitoring link will provide subsystem status to the module level. Checkout equipment with hardwire connections will provide subsystem status to the ORU level during post and preflight function tests. It is assumed that the batteries would be recharged after every flight. Solar arrays, if added, may require cleaning after 3 or 4 years of operation.

Consumables that must be resupplied include propellants, propellant pressurization gas, and gas for the cold gas RCS. Resupply may be accomplished after every flight or on an as-needed basis.

OMV service life has been baselined as 10 years with ground refurbishment after 5 years. Periodic maintenance examples include battery changeout and catalyst bed changeout for monopropellant systems. All other maintenance activity would be contingent on component failure.

A time line for OMV turnaround would require approximately 100 man-hours over a 4-day period. This time includes 32 man-hours for repairs and 32 man-hours for payload (satellite service equipment) mating. The OMV may be operated from the Station during proximity operations.

The time lines are based on the following ground rules and assumptions:

(a) Four man crew: Three crewmen involved with OMV activities, one man assigned to other Space Station activities;

(b) One 8-hour shift per day;

(c) Crew can work an 8 hour shift without scheduled lunch or rest break;

(d) OMV turnaround requires EVA;

(e) Two men required for all EVA for safety, a third man suited-up for EVA emergency backup;

(f) EVA restricted to a maximum of 8 hours in a 24-hour period per crew man;

(g) Pre-breathing for EVA has been minimized;

(h) Automatic interface mating (electrical and fuel) provided; and

(i) Plans and procedures are stored in the computer, and crew has been pre-briefed.

3.6 SPACE STATION/OTV INTERACTION SCENARIO

A number of studies and planning efforts indicate that a space-based OTV is needed to provide high-energy transportation capability for orbit transfer from the Space Station. The OTV capability is planned to be provided several years after the Space Station System IOC and could perform GEO deliveries and servicing missions as well as solar system escape.

A space-based OTV requires that servicing be performed in space (including refueling, repair, and checkout) as well as other support and mission functions (including payload/OTV integration, docking/berthing, handling, logistics, storage, and pre-launch/post-launch processing). Depending on final OTV design, delivery of the OTV to the Space Station by the STS could be as a complete assembly or as separate components requiring assembly at the Space Station. The OTV baseline configuration may be of modular construction with simplified and standard interfaces for ease of maintenance. Figure 3-3 illustrates two of the conceptual OTV configurations.

It may consist of a main engine, lightweight propellant tanks, an attitude control system, avionics for guidance, navigation, and control, an aerobrake, load carrying structure, a power source, thermal control, fluid management, and docking subsystems.

Table 3-4 is a summary of the OTV turnaround requirements in terms of overall Space Station operations and associated interfaces.

Maintenance requirements include such operations as handling, assembly, servicing, repair, inspection, and checkout.

A typical OTV turnaround would include:

- Berthing of OTV by remote manipulating system or OMV;
- Deservice of residual fuels;

FIGURE 3-3
SPACE-BASED OTV CONCEPT EXAMPLES

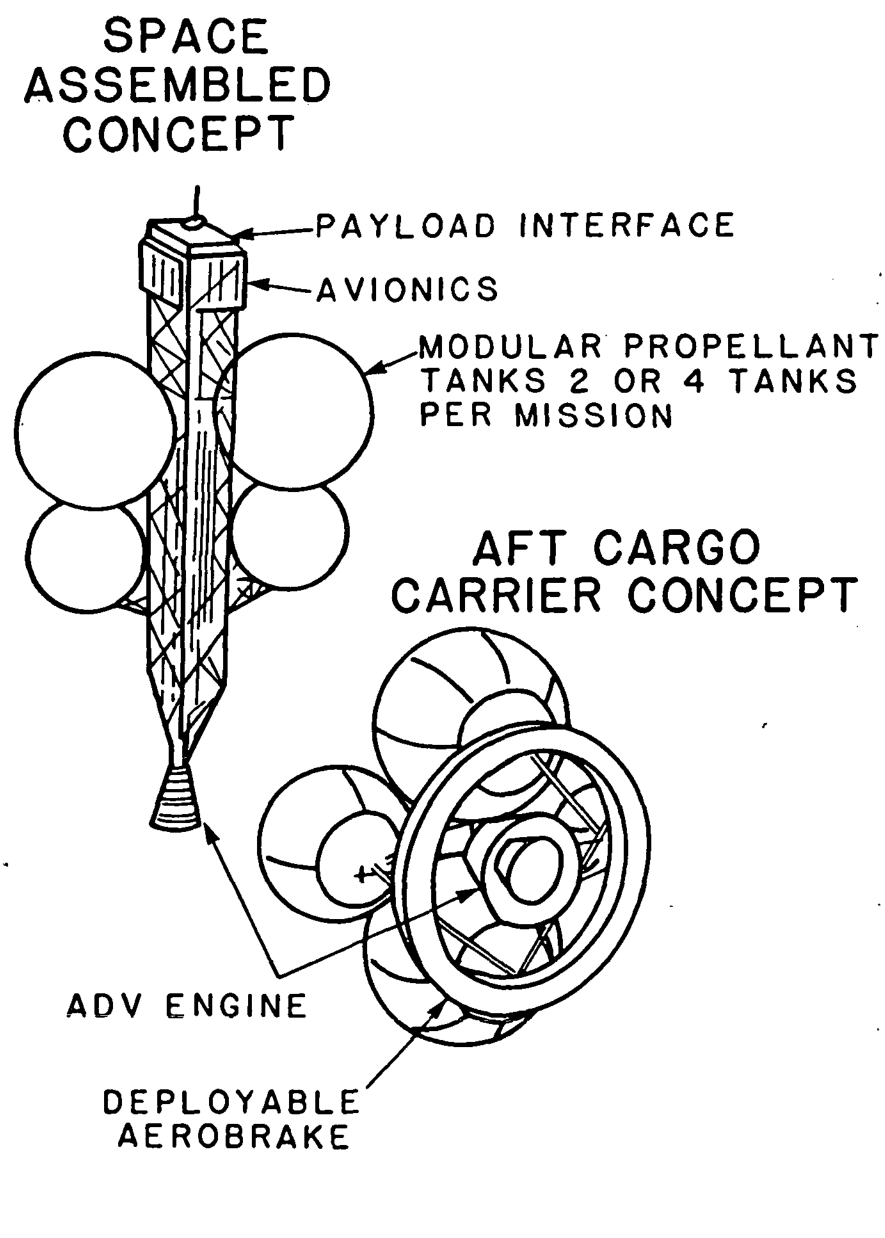


TABLE 3-4

SPECIFIC REQUIREMENTS (OPERATIONAL AND PHYSICAL) FOR OTV ACCOMMODATIONS

- STATION/TECHNOLOGY MISSION INTERFACES
- BERTHING STRUCTURAL AND CONTROL INTERFACES
- MANIPULATOR/CRANE SERVICES
- TELEOPERATOR SERVICES
- FUEL STORAGE
- COMMAND CENTER CONTROL EQUIPMENT
- LIGHTING AND VIDEO COVERAGE
- POWER DEMAND
- HANDLING EQUIPMENT
- MAINTENANCE, REPAIR, AND CHECKOUT EQUIPMENT AND TOOLS
- RENDEZVOUS INTERFACE
- CREWMEN SKILLS
- EVA AIRLOCK

- Installation of access equipment;
- Test, checkout, and refurbishment of OTV systems;
- Payload mating and integration;
- Fueling;
- Countdown operations;
- Deployment; and
- Reconfiguration for new mission (hardware and software).

This turnaround is expected to require approximately (TBD) man-hours over a (TBD)-day period based on the same ground rules listed for the OMV in Section 3.5. An example of a turnaround scenario is depicted in Figure 3-4. The OTV may be operated from the Station during proximity operations.

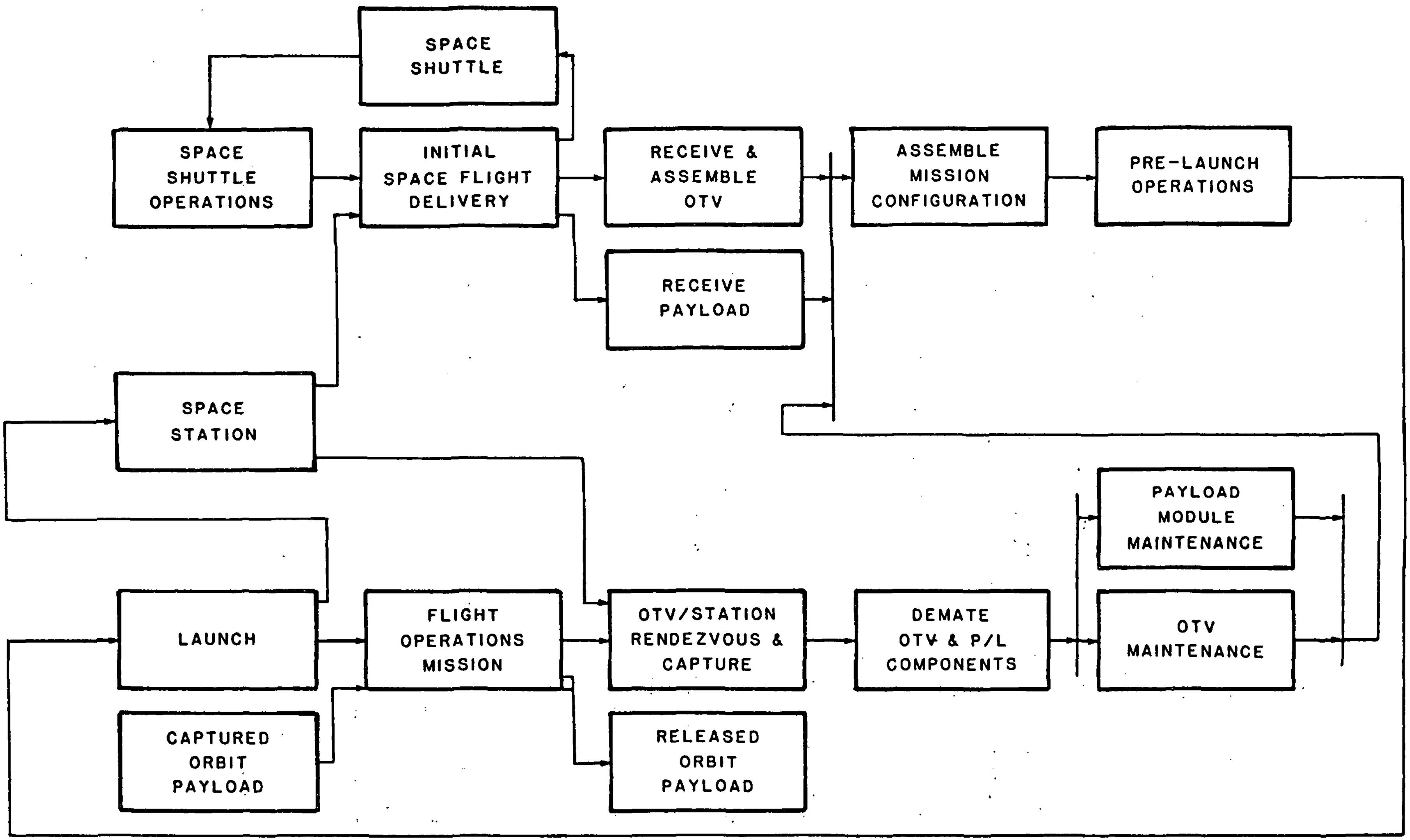
3.7 SECURITY

Security considerations will incorporated into the Space Station Program in a manner consistent with the threat, vulnerabilities and countermeasures that may exist in the 1990's. Consideration will be given to the overall security of the ground space station support facilities, communications in general and the various space station related activities, platforms, vehicles, maneuvering systems and satellites.

Studies will be performed to provide the threat and vulnerability analysis and identify existing and promising technologies related to security of the space station. These studies will be conducted to insure the security system requirements are fully integrated with the Space Station development.

In anticipation of DOD utilization of Space Station, potential system requirements will be developed.

FIGURE 3-4
SPACE-BASED OTV OPERATIONS



Secure communications will be a major concern with the Space Station. A system will be developed to permit secure command and control for the ground station but allow customers to communicate with their on-board payloads. A dual system of encrypted communications will be necessary to separate commercial proprietary and national resource data transmission. New technology, such as laser transmission systems, will be considered to ensure state-of-the-art communications during the 1990's.

4.0 PAYLOAD AND MISSION OPERATIONS

4.1 GENERAL

A payload is "the total complement of specific instruments, space equipment, support hardware, and consumables required to accomplish a discrete activity in space." A payload, then, may be large or small, complex or simple. Figure 4-1 describes, in block diagram form, the System that may be flown. From this, it can be seen that the variety of payload possibilities for this System are rather large. The payloads may range from simple instruments attached to or installed inside the Space Station itself to large geostationary spacecraft and interplanetary probes.

For convenience in discussing them, payloads will be categorized as follows:

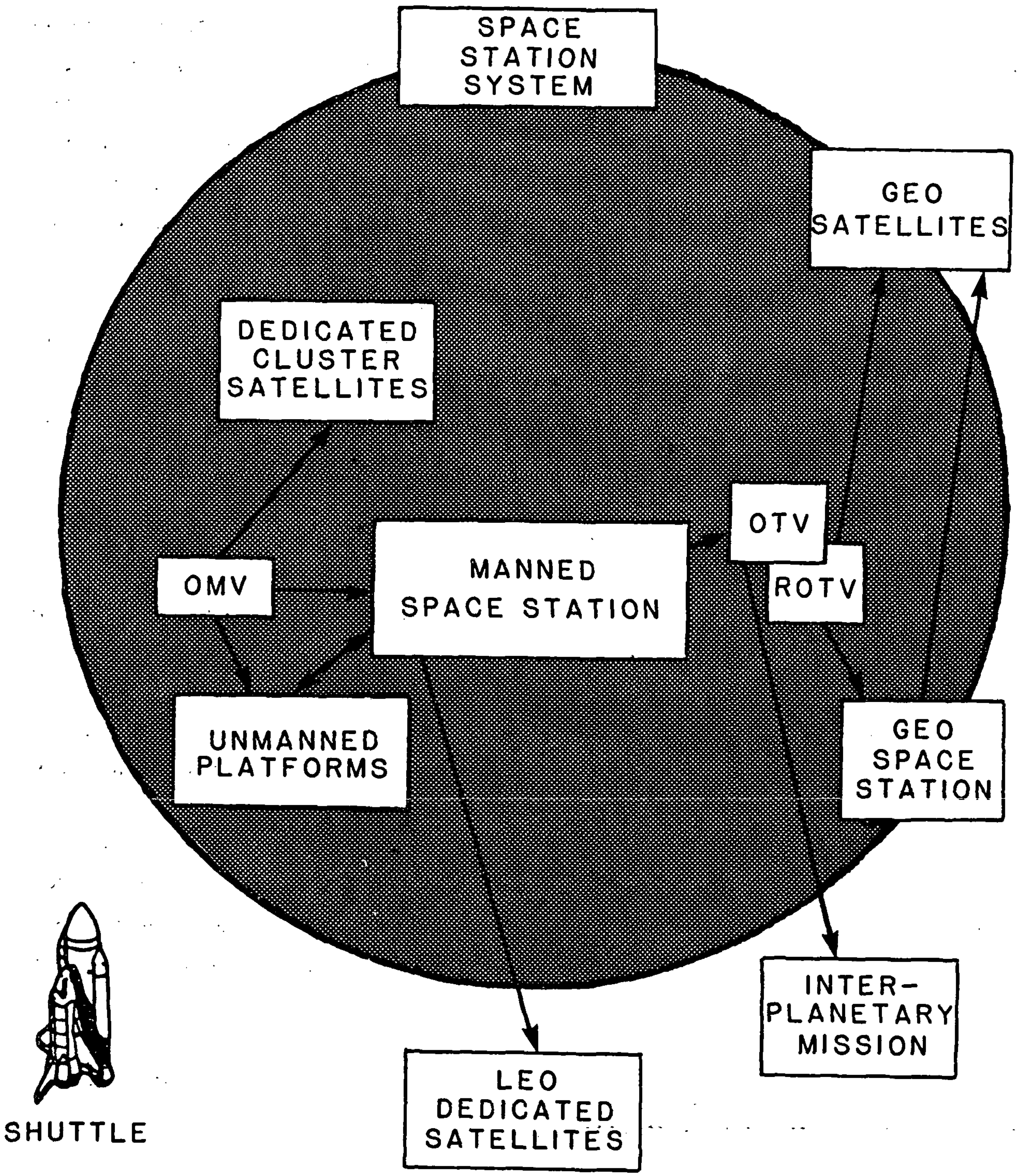
- Tethered payloads;
- Space Station attached payloads (interior or exterior);
- Co-orbiting and polar platforms;
- Low-Earth orbiting (LEO) spacecraft;
- Geosynchronous spacecraft; and
- Earth-escape payloads.

These payloads may or may not need power, thermal control, commands, data services, control, assembly, repair, or replacement from the Space Station. The Space Station System will need to provide some sort of low-Earth orbit maneuvering system for payloads, orbital transfer vehicles (OTVs), and a Station crew maneuvering system as suggested in Figure 4-1. These services will be described as they apply in the discussion of the various payload types as previously categorized.

With the possible exception of Earth-escape payloads, each category of payloads may include commercial and national security payloads. Such payloads will have special needs regarding secure command and data transmission and

FIGURE 4-1

MANNED SPACE STATION - CORE ELEMENT OF THE SPACE STATION SYSTEM



proprietary protection. The Space Station on-board command and data handling system will provide secure communications as required for normal and emergency operating conditions. This includes command authentication by the on-board control system of the command links. It is expected that any payload requiring encrypted data handling and communication will include the encryption and decryption capability in their payload. The use of encryption/decryption will not impact other payload users. At the same time, the Space Station System must be designed to allow this capability to be installed by payloads. Routine command and data handling from NASA ground centers and on-board the Space Station may not require encryption and decryption. Consideration must also be given to the fact that these kinds of payloads may be part of a larger, non-secure system. Provisions for secure or proprietary operation by a Space Station crew member may be required.

Some payloads may require or desire to operate autonomously (i.e., operation independent from the control of the Space Station). Where desired, payload customers will be able to communicate directly with their payloads without going through the Space Station data handling system or the TDRSS. If payload customers desire direct access to payloads, this will be provided with a minimum of operating constraints subject to safety and compatibility. It is expected that each such payload would then operate within a pre-defined envelope of resources. Interaction with other payloads, if desired by the customers, should not be precluded.

Commands to attached payloads may go through the Space Station control center or go directly to the payloads. The capability to routinely inform the crew of all ground command activity to payloads on the Space Station will be provided. Most payloads that will use the Space Station data system desire that the system be transparent to the payloads. For many payloads, including Department of Defense (DOD) type, the requirement will exist for some payload operation and control during unmanned periods or when the crew is asleep or working with other payloads.

Figures 4-2, 4-3, and 4-4 illustrate payload interface concepts that simplify Space Station-to-customer interfaces.

FIGURE 4-2
PAYLOAD INTERFACES

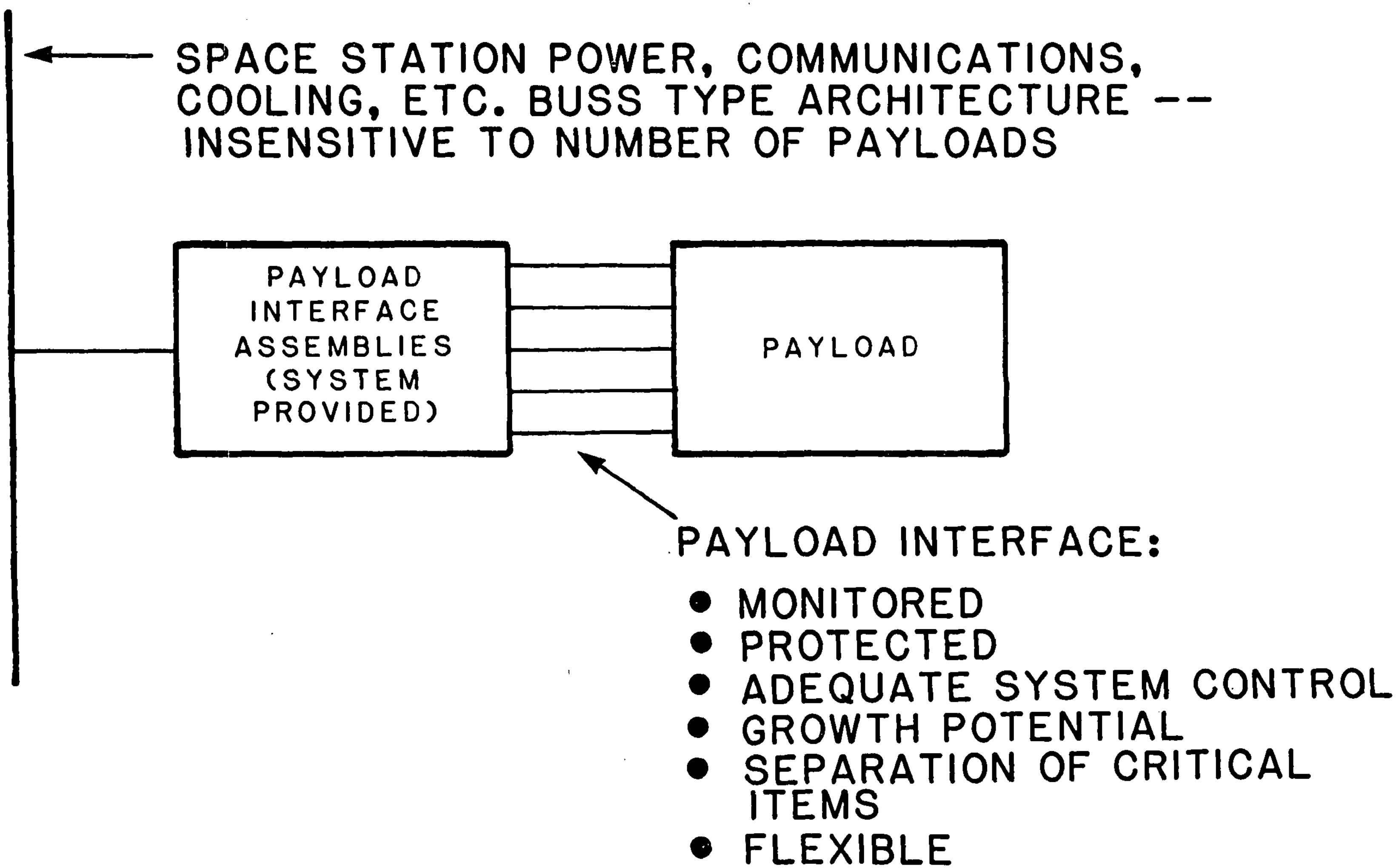


FIGURE 4-3

TRANSPARENT DATA SYSTEM COMMUNICATIONS

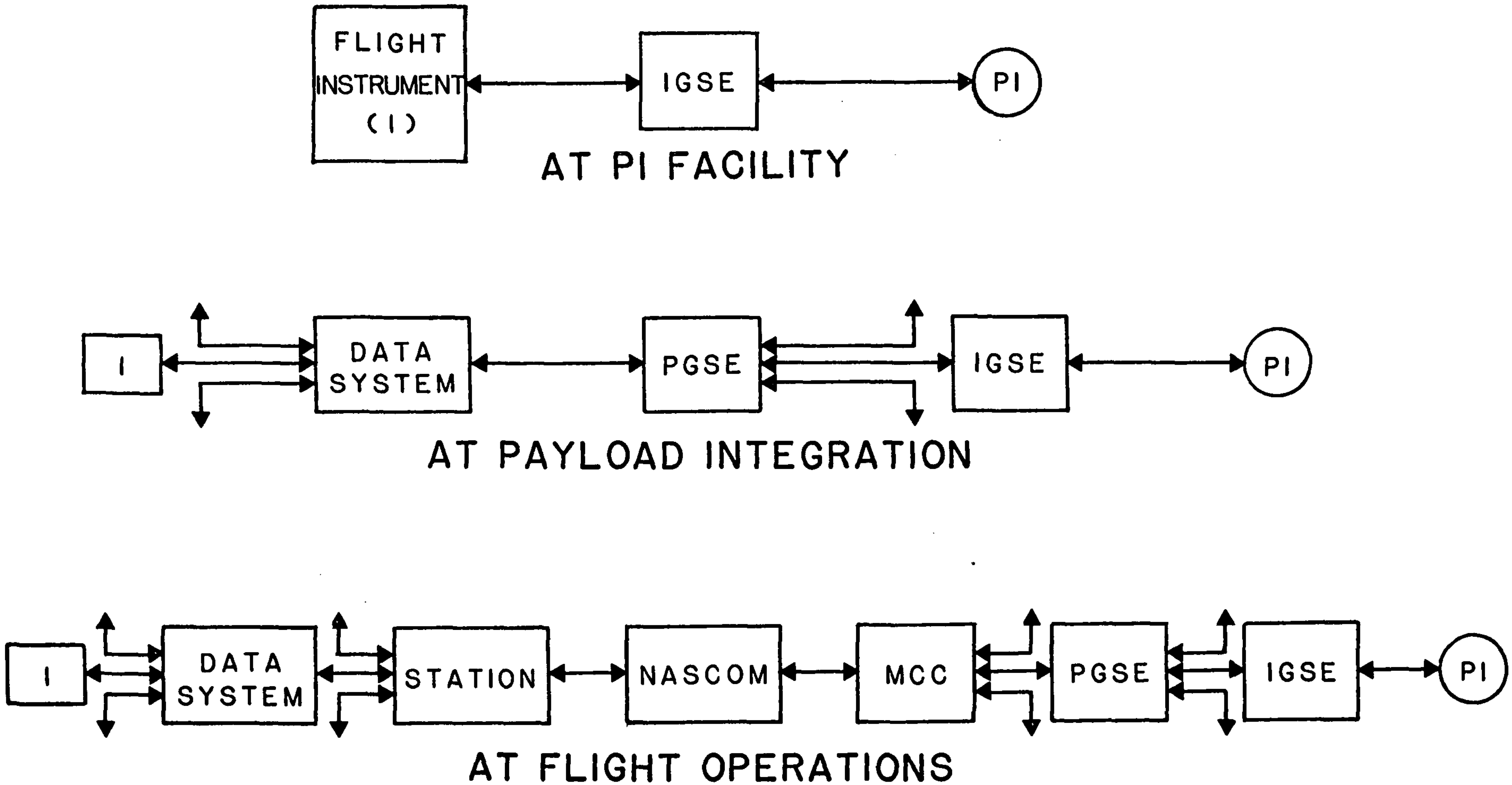
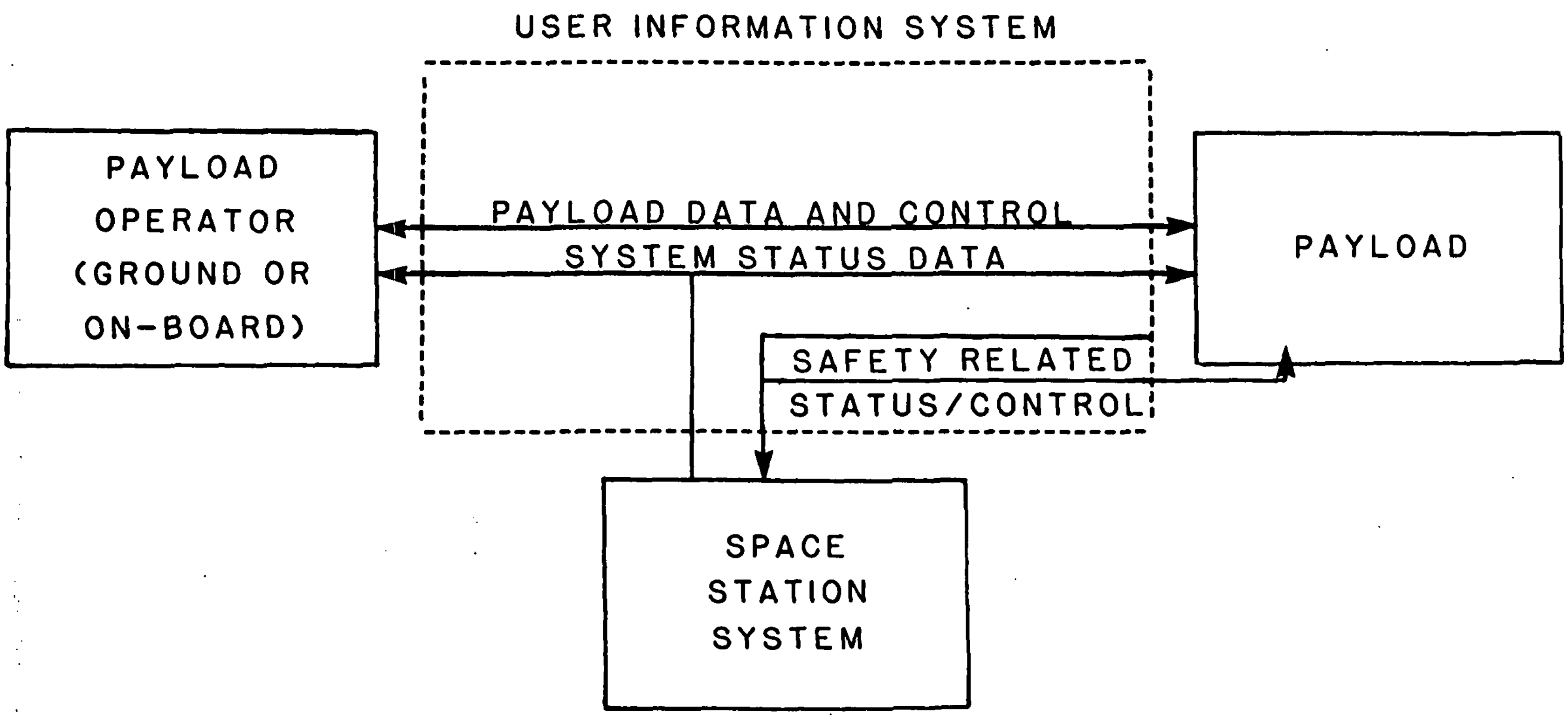


FIGURE 4-4
DATA AND CONTROL



Payload health, safety, status, and science information may be received and displayed on-board the Space Station for monitoring, evaluation, and control activities. Since the Space Station will operate on-orbit for an indefinite period, will support a large number of time-phased payloads during its lifetime, and will require diverse methods of on-board command and data display, the on-board command and monitor philosophy of the payload may require that the customer provide dedicated command and display equipment mounted within the Space Station for the duration of a particular payload stay. Responsibility for integration (including customer-unique impacts) belongs to the customer.

This equipment will normally be the same equipment used for payload pre-launch operations on the ground and will be designed in accordance with Space Station program requirements to ensure safety and flight crew operability. Through this philosophy, it is hoped that: (1) Complex interfaces between the Space Station and payloads may be avoided; (2) the customer will be free to design command and monitor equipment suited to his application; (3) the latest technology can be used by the payload project; and (4) payload command and monitor equipment may be verified with the payload before flight.

Routine servicing, maintenance, repair, and changeout for payloads will be performed by the Space Station crew members either directly or by operating remote manipulator systems. Examples will be given in the specific payload-type discussions that follow. Space Station crew activities required by payloads will be coordinated with the ground and included in the integrated time line. Payloads requiring maintenance or servicing will be provided servicing standards by the Space Station program.

4.2 SPACE STATION ATTACHED PAYLOADS

The most obvious payloads for the Space Station System are those attached either internally or externally for their operation. This class of payloads may potentially be the most demanding on the capabilities and services of the Space Station and its crew. They may range in size from small, "carry-on" instruments to large assemblies mounted on rotatable pallet-like structures attached to a berthing port on the Space Station. They may have simple or complex interfaces with the Space Station and require a little or a lot of the available Space Station resources.

4.2.1 Preparation and Assembly

The initial Space Station may be launched with payloads installed inside the pressurized volume. These payloads will be integrated and checked out before launch at the launch site, much like Spacelab payloads are processed today. It is not expected that there will be significant assembly activity on-orbit for this "first load" of payloads.

Externally attached payloads will be carried on-orbit on Shuttle flights that follow the delivery of the pressurized section of the Space Station. These payloads and payloads to be installed in the pressurized volume subsequent to the initial delivery will be shipped to the launch site where they will undergo appropriate readiness tests for launch. The payload may be connected to a Space Station simulator or interface unit to verify that all the payload systems will operate normally when attached in or onto the Space Station on-orbit. This is primarily to verify the compatibility of the payload interface with the Space Station element to which it will attach.

Upon delivery to orbit and docking of the Orbiter with the Space Station, the Space Station crew will assist the Orbiter crew in removing the payload from the Orbiter bay using the remote manipulator. The Space Station crew will attach the payload in its operating position using whatever required equipment and the payload specialists will perform a functional and operational checkout of the payload. If all systems are normal, routine payload operations can begin.

4.2.2 Payload Operations

Space Station attached payloads must at least be tolerant of man's presence and, in fact, most of them will require to some extent the active involvement of the Space Station crew. Some of these payloads may require real-time diagnosis or evaluation of science/application data with subsequent equipment reconfiguration, periodic collection of samples, changeout of specimens/samples, and the monitoring of some key parameters. The extent of Space Station crew involvement in payload operations will be determined on a payload-by-payload basis and will be pre-planned.

Planning for the operations of attached payloads will be done by the payload ground personnel in consultation with Space Station specialists while control of the operation may be by the Space Station payload specialists or by the payload ground personnel. Time lines for the operation of payloads on the Space Station will be developed using inputs from the payload developer/customer and Space Station specialists. Integrated time line activities will be developed through iterations between the Space Station crew and the ground. This will require regular coordination between the ground support personnel and/or customer and the Space Station crew. Activity time lines will be maintained by the shared on-board/ground data management system. Impacts to the time line due to additions, deletions, and changes in activity will be available on the Space Station and on the ground. Ground commands to the payload may be transmitted directly if no potential hazards or operational interferences are involved. Some payload developers/customers will require the capability to develop, checkout, and operate software for their payloads without NASA intervention but must do so within the operating and safety guidelines established for the Space Station.

4.2.3 Payload Servicing And Repair

When it is determined that an attached payload requires maintenance or repair, the payload specialist will take the necessary action to access the payload. For externally mounted payloads, this will normally require EVA. The payload will be safed, the payload specialist will perform the required maintenance (whether repair or service), and with assistance from the other crewmembers, will then perform payload checkout and return the payload to normal service. Obviously, this process will be considerably simpler for payloads mounted inside the pressurized volume of the Space Station.

During servicing and repair operations, the Space Station may be in communication with the ground. The ground will advise on procedures or solutions to unexpected problems encountered and will generally be available to assist the

Space Station crew as needed. Service and repair tasks may result from pre-planned, scheduled maintenance or from contingencies such as unexpected cryogenic depletion, battery malfunctions, or electrical anomalies. When problems are detected, the ground will support the Space Station crew as required relative to identification of the problem, the Space Station crew role in the repair, procedures or use, and the time line for the repair. Pre-planned scheduled maintenance or service events will be coordinated with the payload customer. Film and/or samples will be brought from the payload(s) and returned to the ground by the Orbiter.

4.2.4 Payload Changeout And Replacement

As a planned or contingency event, attached payloads may be changed out and new payloads installed. A payload that is to be returned to Earth will be powered down and safed by the payload specialists. The payload will be removed from its Space Station position and prepared for return to Earth by the Orbiter.

The Space Station crew will be briefed by the ground for the required installation, checkout, and operation of a new payload being brought by the Orbiter from the ground for changeout. Payloads being changed out or replaced will be inactive during that operation and no science/application data will be transmitted during that time. Checkout of the new payload will normally be done by the Space Station payload specialist, but assistance may be provided by the other crew members or the ground.

During critical periods when the Orbiter is in close proximity to the Space Station, ground control will be coordinated with Space Shuttle Mission Control. For safety reasons, ground commanding to the Space Station or attached payloads during the Orbiter-attached or proximity phase will be coordinated with the Space Shuttle Mission Control.

4.2.5 Support Elements

Support needed for attached payloads includes all normal services of the Space Station plus supply and transfer from the Orbiter, possible EVA by Space

Station crewmembers, and use of a remote manipulator either on the Orbiter or on the Space Station.

Examples of services for payloads will include electrical power (e.g., 60 Hz, 400 Hz, and dc), heat rejection, and data transmission to the ground. Onboard command and data display will be accomplished through the standard work stations except where payload benefits to the customer may be compromised. Space Station parameters such as ephemeris, timing, and pointing data will be provided to the payload through a standardized interface with the Space Station computer system.

The Space Station will provide a transparent data system for payload use. The Space Station may also provide communication systems as a standard facility service for payloads.

4.3 CO-ORBITING AND POLAR PLATFORMS

Platforms are unmanned structures designed to carry and support payloads that require exposure to space or that cannot be attached to the Space Station due to size, shape, or resource requirements. Such a platform can be connected to the Space Station by a tether, maintained in a compatible orbit so that it can be serviced easily by the Space Station crew, or put in a high inclination orbit and serviced by the Orbiter. It is expected that the free-flying platforms will generally be independent of the Space Station for its operation, although they may use the Space Station as a command/data link to the ground. Payloads requiring a platform are those that are too large or have power, cooling, pointing, orbital or stability requirements, or contamination requirements exceeding what is available in or on the Space Station. A platform may contain a single, large payload or a number of compatible, small payloads.

4.3.1 Preparation And Assembly

Like the Space Station itself, it is assumed that the platform will be launched as a Shuttle cargo with all systems and initial payloads installed on the platform. The payloads will be installed, integrated with the platform, and checked out at the launch site before launch. Facilities like those currently used for processing horizontally-installed payloads should be adequate for processing the platform and its payloads.

Payloads to be installed on the platform after the platform is delivered to orbit will be processed on the ground and delivered to orbit by the Shuttle in much the same way as those installed on the Space Station in orbit (see Section 4.2.1). Platform interface simulation will be required to assure the payload will fit and function properly when installed on-orbit.

For platforms in the vicinity of the Space Station, on-orbit installation of payloads can be done from the Space Station or from the Orbiter. For an Orbiter-assisted installation, the procedure is as follows:

> After berthing, the Orbiter RMS is used to remove the payload from the cargo bay, and the payload is attached to the platform, The Space Station payload specialist and the ground monitor this activity. Before the platform is released by the Orbiter, the payload is given a cursory checkout. The Orbiter then moves away from the platform and begins a stationkeeping mode while the ground and the Space Station payload specialists perform a complete functional and operational checkout of the payload before beginning normal operations. After all payload systems are checked out, normal payload operations are started by the Space Station payload specialist.

For installation by the Space Station crew, the platform must be in the vicinity of the Space Station. Crew members would, as an EVA, transport the payload to the platform using something like the manned maneuvering unit (MMU). Installation and checkout of the payload would be performed in much the same way as if installed from the Orbiter. The Space Station crew would return to the Space Station and normal payload operations would begin.

4.3.2 Operations

The on-orbit operation of a platform will generally be similar to the operation of an LEO satellite. A ground control center will be the focal point for all platform-related activity; however, the platform will be designed to be capable of payload communication with the ground or the Space Station. Since it is possible that the platform could be operational before the Space

Station, the platform communication system must be compatible with the TDRSS and the Space Shuttle.

The Space Station crew and the on-board data handling system may be required to perform data processing and/or data compaction for some platform payloads with subsequent retransmission to the appropriate ground control center. This could be used to alleviate problems and complications associated with the transmission and ground handling of the high data rates and subsequent data volume for ground processing. A requirement for this method of communication will also impose a requirement that the platform keep station with the Space Station. The customer having this requirement would be subject to constraints imposed by the Space Station.

For cases in which a payload has its own communication system, the payload may desire to communicate directly with ground (either through TDRSS or with a ground station). Such an operation will be subject to safety constraints imposed by the platform and/or the Space Station.

4.3.2.1 Tethered Platform Operations

For the option in which one or more platforms are tethered to the Space Station, operation of the platforms and/or their payloads would be similar to operating attached payloads. The payloads would have option communicating through the Station or directly through TDRSS to the ground.

4.3.3 Platform Servicing And Repair

Payload servicing may include such things as film/sample retrieval, instrument calibration/recalibration, or consumable resupply. Since the platform may become operational before the manned Space Station, initial payload servicing and repair will probably be performed using the Orbiter. When performed from the Orbiter, the servicing/repair may be done in the Orbiter direct mode, remotely by OMV or platform attached RMS, or by an Orbiter crew member using the MMU to access the payload. When the payload to be serviced is reached, the individual payload(s) or the entire platform will be deactivated as required for safety and serviceability and the service/repair performed.

Following this activity, the platform will be checked out before the Orbiter/ crew member leaves, and it will then be reactivated.

If the platform is co-orbital with the Space Station or can be reached by the OMV, other servicing options become available. For servicing/repair by the Space Station crew, either the MMU or the OMV may be used to gain access to the payload of interest. The OMV will be used to transfer payloads from the platform to the Space Station or to transfer the entire platform to the Orbiter. The MMU may be used to transport a crew member to the platform and the payload of interest. The required service/repair operations may be done at the Space Station or at the platform. The repair/servicing scenario then follows that described in the previous paragraph. During servicing/repair by the Space Station crew, communications with the platform will be through the manned Space Station.

Polar platforms will be serviced by the Orbiter.

4.3.4 Payload Checkout Or Replacement

The options of using the Orbiter and its crew or the Space Station and its crew for servicing and repair activities for a payload on a platform apply also to the changeout or replacement activities. The Orbiter option will require that the Orbiter be in the vicinity of the platform, the RMS be used to remove the target payload, and the RMS be used to replace it or install a new payload in its place. As an option, the work can be performed by an EVA crew member using the MMU and the appropriate hand tools.

If the new or replacement payload is brought to the Space Station by the Orbiter, then the Space Station crew may use EVA to accomplish the replacement or changeout, using the MMU for transportation. An alternative is using the OMV to transport the replacement payload to the platform, to remove the target payload, to install the replacement payload on the platform, and to return the replaced payload to the Space Station.

For any mode of accomplishing the job, the payload to be replaced will be deactivated before removal while the rest of the payloads on the platform continue to operate unless hazardous to the OMV or the crew. Following installation of the new payload, it will be checked out before being fully activated to its operational state.

4.3.5 Support Elements

In addition to the normal services of delivery and storage supplied by the Orbiter and the Space Station, platform payloads will need the MMU for crew EVA and/or the OMV for transport between the platform and the Space Station.

4.4 LOW-EARTH ORBITING SPACECRAFT

LEO free flyers, or spacecraft, have many similarities to an LEO platform but at the same time are distinctly different. It is presumed that the LEO platforms are always in an orbit compatible with the Space Station orbit and that they somehow are kept "on-station" with the Space Station for ease in servicing and to share in communication capability. No such constraints are applied to the LEO spacecraft. They may or may not be in the same orbit plane as the Space Station, and the free-flying spacecraft are completely autonomous from the Space Station. The anticipated usage of the Space Station by this class of spacecraft is for storage and subsequent assembly before transfer to final orbit, as well as for planned or contingency repair and payload replacement when orbits are compatible.

4.4.1 Preparation And Assembly

LEO spacecraft will be shipped to the launch center and prepared for launch in much the same way as they are today. They may be placed into orbit directly with the Orbiter plus the additional propulsion, or they may be delivered to the Space Station for assembly and checkout before being delivered to orbit with the OMV or other orbit transfer stage. In this case, assembly could mean the erection of a large structure (antenna) or the joining of two or more elements delivered to a Space Station orbit by the Orbiter. In such cases, it is expected that the work on-orbit would be accomplished by an EVA crew with the support of the customer. An important aspect of this assembly work will be the operational checkout of the spacecraft and payloads before committing the spacecraft to orbit insertion.

4.4.2 Payload Operations

Since the LEO spacecraft is intended to operate in orbits that may or may not be compatible with the Space Station, it is not expected that the Space Station will have any role in the operation of an LEO spacecraft. Payload operations will be conducted essentially the same way that they are today with free-flying spacecraft.

4.4.3 Payload Servicing And Repair

At some time during the mission of an orbit-compatible, free-flying satellite, routine servicing or repair of a malfunction may be required. The Space Station crew will have the capability to repair or service these payloads. The capability to perform this activity may be available on-board the Space Station. In some cases, it may be desirable to have the ground perform the orbit determination and targeting required to reach the spacecraft. The crew will then use the OMV or MMU as appropriate to reach the spacecraft for servicing. Ground control of the OMV will also be available.

Repair of the free-flying spacecraft can also be accomplished by the Orbiter crew either in a Shuttle direct mode or with the use of an MMU and/or OMV. In fact, when an LEO spacecraft is in an orbit that is incompatible (non-coplanar) with the Space Station, the Orbiter (possibly with an OMV) or OTV will be the only means available to service or repair its payloads. Figures 4-5 and 4-6 show servicing options for co-orbiting and non-co-orbiting spacecraft and platforms.

FIGURE 4-5

SPACECRAFT AND PLATFORM SERVICING OPTIONS, CO-ORBITAL WITH STATION

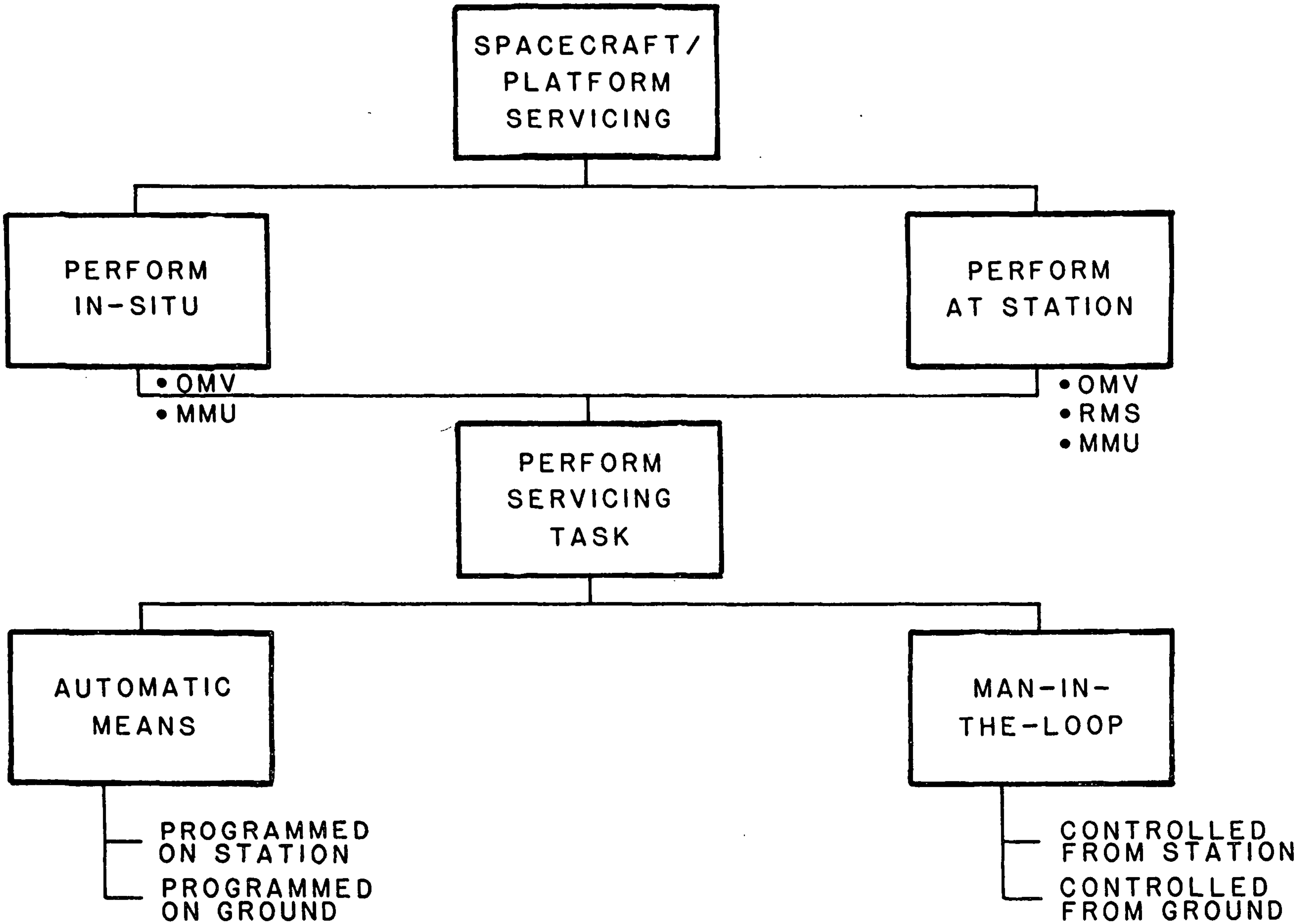
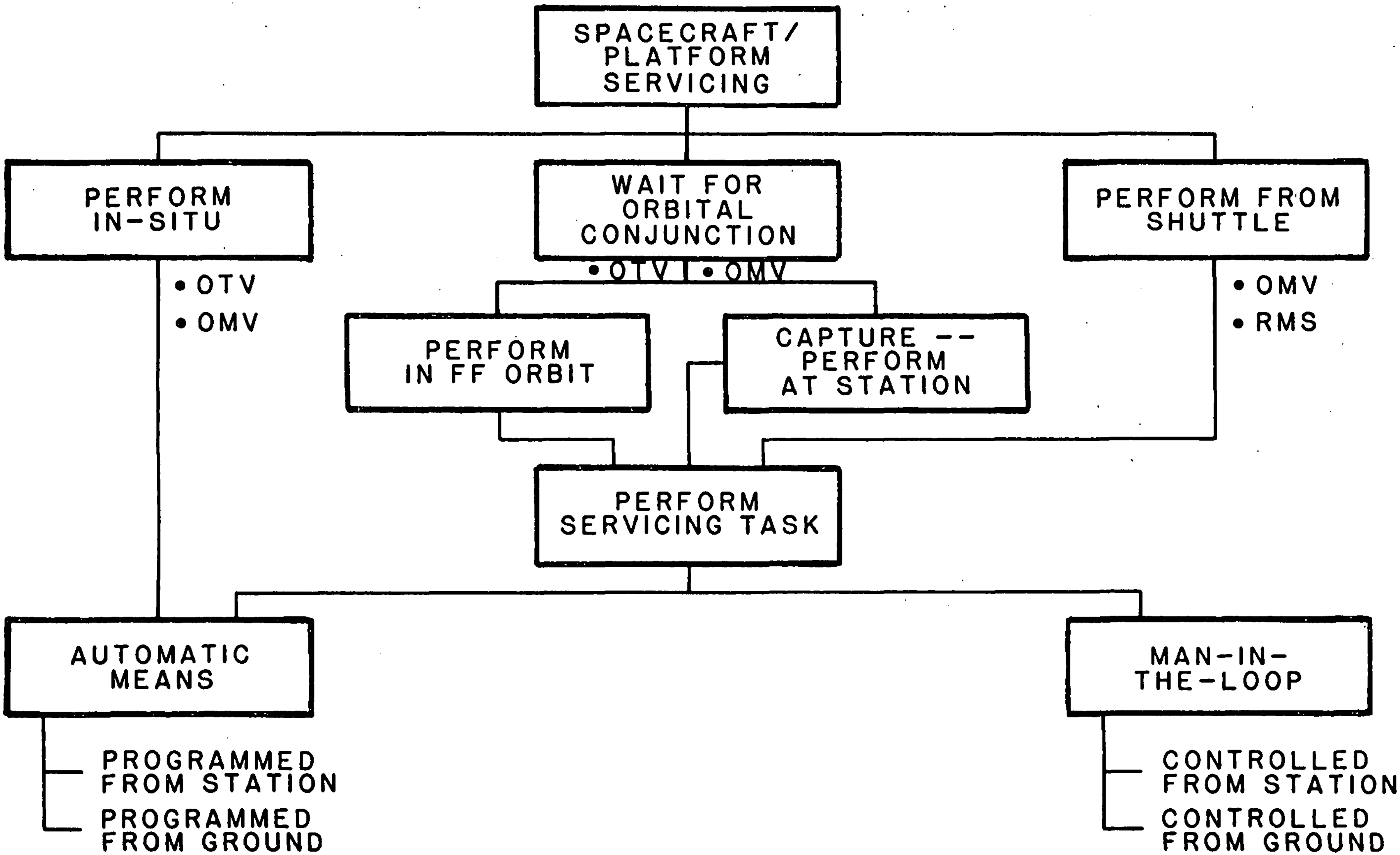


FIGURE 4-6

SPACECRAFT AND PLATFORM SERVICING OPTIONS, NOT CO-ORBITAL WITH STATION



4.4.4 Payload Changeout Or Replacement

If the LEO spacecraft is in an appropriate orbit, the payload replacement and changeout activities will be the same as those described in Section 4.3.4 for the platform. For spacecraft in orbits incompatible with the Space Station, the Orbiter will be used to perform the activity using techniques and equipment being developed for Space Shuttle repair of satellites and payloads.

4.4.5 Support Elements

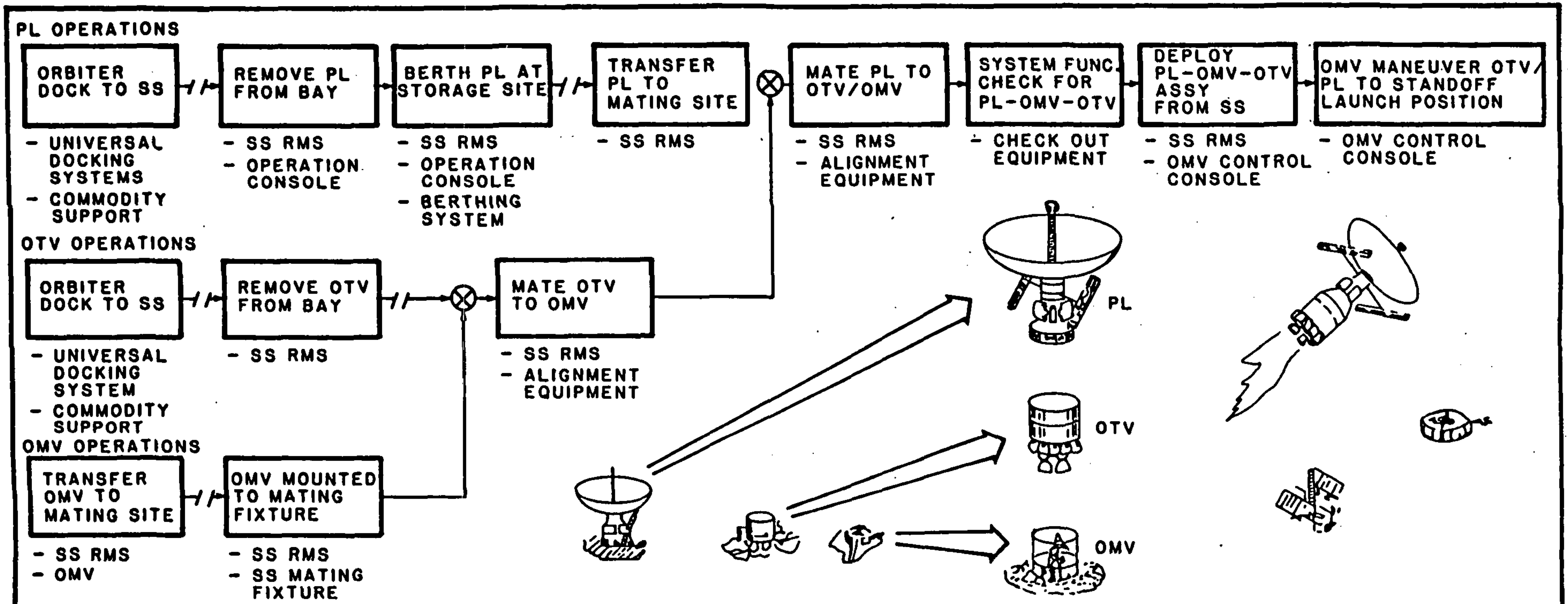
It is expected that free-flying spacecraft will be designed so that repair and changeout activities are possible and practical. Besides normal Orbiter services, the LEO spacecraft may require the use of EVA and associated maneuvering systems for assembly on-orbit. An OTV may be required to place the spacecraft in the desired orbit. Subsequent repair and/or changeout activity could require use of the OMV and MMU.

4.5 GEOSTATIONARY-EARTH ORBIT SPACECRAFT/PLATFORMS

A significant aspect of a Space Station System will be to serve as a base for space construction and for staging of elements being launched to higher energy orbits such as GEOs. In order to perform these functions, it is necessary for the Space Station System to include a warehousing function for storage of materials and supplies. For the Space Station System to serve as a launch facility for geosynchronous missions, the warehouse function must also provide for the storage of propellants used by the launch vehicle(s) as well as docking support for these vehicles.

An OTV will eventually be made a part of the Space Station system and will be available for use by this class of spacecraft/payload. Figure 4-7 shows a typical payload-to-OTV assembly.

FIGURE 4-7
FUNCTIONAL ANALYSIS - ASSEMBLY PAYLOAD TO OTV



GROUNDRULES	SUPPORT REQMTS.		
- OMV	- UNIVERSAL DOCKING SYSTEM	- ALIGNMENT EQUIPMENT	- COMMODITY SUPPORT
- OTV	- BERTHING SYSTEM FOR:	- OPERATION CONSOLE	- REPL. PARTS FOR OMV & OTV
	•PL •OMV •OTV	- OMV CONTROL CONSOLE	- SS RMS
	- CHECK OUT EQUIPMENT	- MANNED SUPPORT	- SS MATING FIXTURE

4.5.1 Payload Preparation And Assembly

It is assumed that there is an OTV based at the Space Station that will be used to insert the payload/spacecraft into geostationary orbit. The payload/spacecraft will be prepared for and launched into LEO (Space Station orbit) by the Orbiter. Preparations for this will be similar to what is done for Shuttle-launched spacecraft. One difference is that the geostationary spacecraft will be launched attached to an upper stage and will have to be carefully tested and checked to assure its ability to mate with the interface available on the OTV and the Space Station. This will require some kind of ground simulator to verify the spacecraft's ability to meet these mechanical and functional interfaces.

In anticipation of the arrival of the geostationary spacecraft at the Space Station, the OTV will be serviced and prepared for mating to the GEO spacecraft. The GEO spacecraft will be mated to the OTV and a complete checkout of the interfaces will be conducted. The OTV will then be fueled and final checkout of the spacecraft and the OTV operation will take place. Following flight configuration of the spacecraft including antenna deployment, if necessary, the OTV/spacecraft will be moved away from the Space Station (to prevent damage) and launched.

After the spacecraft is properly located in geostationary orbit, the OTV will release the spacecraft and return to the Space Station where it will be serviced and prepared for the next use. The details of this servicing activity were covered in Section 3.6.

4.5.2 Payload Operations

Operation of geostationary payloads will be the responsibility of ground control. The Space Station will only be involved in the operations related to checkout of the payload/OTV interface before OTV launch.

4.5.3 Payload Servicing And Repair

The Space Station will serve as a base to service spacecraft and payloads in GEO. Several options exist to access and service these payloads. An OTV may be used to transport a crew to the satellite and provide service to the payload in place. The OTV may be used to return the payload to the Space Station for repair. OMV, coupled with OTV, servicing may occur at GEO. For some situations, it may be desirable to return the satellite to the ground for service or repair. OMV, coupled with OTV, servicing may occur at GEO. This capture and return from GEO will use an OTV. The payload will be brought to the Space Station and prepared for return to Earth by the Orbiter. Planning of opportunities for payload capture by the OTV may be done on-board the Space Station by the Space Station crew.

4.5.4 Payload Changeout Or Replacement

Comments in Section 4.5.3 are appropriate for this paragraph also.

4.5.5 Support Elements

The normal launch and retrieval services of the Orbiter, as well as the full services of a space-based OTV, will be required for geosynchronous payloads. The Space Station is required for staging and checking out the OTV and the OTV/spacecraft combination. This checkout will use the Space Station command and data system. A Space Station remote manipulator or an OMV for moving the OTV/spacecraft away from the Space Station before OTV launch will also be needed.

4.6 EARTH-ESCAPE MISSIONS

This class of mission includes planetary probes and orbiters, solar probes and orbiters, and comet and asteroid missions. Like the GEO spacecraft, they will require the use of the Space Station System largely for staging with an OTV or some other upper stage and final checkout of the spacecraft before launch.

4.6.1 Payload Preparation And Assembly

The requirements here will be the same as those identified in Section 4.5.1.

4.6.2 Payload Operations

The requirements here will be the same as those identified in Section 4.5.2 with the following addition: There will likely be missions that will return samples from the surfaces of planets or asteroids for analysis. These samples must be placed in quarantine at the Space Station before return to Earth or the required analyses must be performed at the Space Station using equipment and procedures brought from Earth by the Orbiter. These represent new operational activities for the Space Station crew.

4.6.3 Payload Servicing And Repair

The only opportunity for payload servicing and repair will be during testing of the payload before launch with the OTV (or other upper stage). Should a payload or spacecraft element fail, repair will be effected by the Space Station crew. A replacement part would be brought to the Space Station by the Orbiter and the Space Station crew, using EVA and the MMU, will make the repair following procedures similar to those discussed in Section 4.2.3 for externally attached payloads.

4.6.4 Payload Changeout Or Replacement

What has been stated in Section 4.6.3 regarding repair is also applicable for changeout or replacement of a payload or spacecraft element while the spacecraft is still near the Space Station.

4.6.5 Support Elements

The same elements discussed in Section 4.5.5 will be needed for this class of mission.

4.7 FORMATION FLYING

For the Space Station to be in a position to service free-flying spacecraft, some type of "formation flying" will be required. Four basic formation flying options have been identified. Two of these options are "close formation" where the spacecraft are kept in the orbit plane within approximately ± 5 km relative to the Space Station utilizing tethered or free-flying spacecraft. The other two are broadly characterized as "rendezvous-compatible orbits." One of the rendezvous-compatible orbit options involved station-keeping within the line of sight (i.e., a downrange distance of approximately 4,500 km). The other rendezvous-compatible orbit option allows drift beyond the line of sight.

The close formation free-flying option requires the spacecraft to make a stationkeeping maneuver daily. Since this maneuvering would create a large workload over a long period of time, this is an undesirable operational approach to formation flying unless automated. Therefore, only the rendezvous-compatible orbit options will be considered as viable candidate concepts for IOC formation flying. Close formation flying may be allowed for short duration cases.

In addition to the Space Station crew involvement in formation flying operations, some of the Space Station subsystems are also involved (e.g., navigation, communications, tracking, data management, electrical power, thermal control, and propulsion). These subsystems must be designed and configured to assure safe and effective formation flying operations.

The major operational concerns to the Space Station are formation flying concepts, formation flying orbital dynamics, spacecraft and Orbiter final approach and departure trajectories, propulsion maneuvers and burn time, contamination and debris, traffic control, and drag modulation.

For the use of textbook spacecraft that maintain formation by virtue of being tethered, the choice of tether orientation and length with respect to the Station is dependent on "g" level desired, contamination and isolation levels desired, and other functions. These will be selected to match the mission.

In operation, the spacecraft would be ruled out from the Station when desired, maintained on-orbit for as long as required, and ruled in when servicing or access to the payloads or spacecraft is desired. The operating berth of the tether would be as short as 1 km or as long as several hundred km.

4.7.1 Constrained To Line-Of-Sight Option

Spacecraft flying in formation with the Space Station will drift ahead or behind the Space Station due to differences in ballistic coefficients and altitudes. If no station-keeping maneuvers are applied to the spacecraft, it will drift beyond the Space Station line-of-sight. However, altitude adjustment to the spacecraft can be made by the Space Station crew to control its excursion profile with respect to the Space Station. The altitude adjustment maneuvers can be commanded by the Space Station crew.

The spacecraft excursion profiles are sensitive to Space Station operational altitude, Space Station and spacecraft ballistic coefficients, atmospheric density, solar cycle time (high or low activity), and station-keeping schedule.

Space Station revisit strategy and schedule will have an impact on payload operations and integral propulsion requirements. In case of spacecraft malfunction or some type of subsystem anomaly, rapid, unscheduled access for servicing and repair may be desirable. Involved in the spacecraft revisit are orbit location and trajectory calculations as well as close proximity rendezvous and docking operations.

4.7.2 Unconstrained To Line-Of-Sight Option

The Space Station and its formation flying spacecraft will drift beyond the line-of-sight relative to each other if there are no scheduled position-keeping maneuver commands to control the drift excursion profile. The drift rate of the spacecraft relative to the Space Station is a function of the ballistic coefficients of the Space Station and the spacecraft and the difference in orbital altitude of the Space Station and the spacecraft. The drift rate and the resulting excursion profile are sensitive to Space Station altitude, Space

Station and spacecraft ballistic coefficients, atmospheric density, solar cycle time, spacecraft altitude, and station-keeping schedule.

Space Station revisit strategy will impact payload operations and integral propulsion system requirements. In case of spacecraft malfunction or some type of system anomaly, rapid access for servicing and repair may be a desirable capability. Involved in the spacecraft revisit are orbital location and trajectory calculations as well as close proximity rendezvous and docking operations.

4.7.3 Traffic Control In Formation Flying

Traffic control refers to the operation of tracking, monitoring, and controlling the position of a selected number of objects within some specific area of interest. For the Space Station, this area of interest is a cone of ± 15 degrees about the fore and aft velocity vector out to 2,000 km and 100% of a sphere of radius of 8 km.

The orbits of formation flying spacecraft constrained to line-of-sight will be under the control authority of the Space Station. This is essential to collision avoidance.

4.7.4 Communications For Formation Flying

Of the formation flying options defined in Section 4.7, the first option would minimize the power and antenna size of the communication system because of the short distance, but would likely produce the biggest interference or shadowing problem requiring multiple antennas. The second option will require larger antennas but shadowing will be less of a problem. The third option requires a relay satellite or independent communications by the platform with the ground. One unique advantage the Space Station offers is a consolidating location for data transfer, thus reducing the number of satellites that would communicate with the TDRSS or its equivalent. The Space Station may have to provide separate communication links for each satellite in the formation.

4.7.5 Tracking For Formation Flying

Two tracking issues of formation flying are the position of each satellite and rendezvous and docking. Some candidate systems for determining position of the Space Station elements are a Global Positioning System (GPS), Tracking and Data Relay Satellite System (TDRSS) Space Sextant, and ground tracking. There are at least two alternatives for determining the position information. One method would have each satellite with an independent positioning system. The other method, called relative positioning, would have the main position system located on the Space Station with each formation flying spacecraft determining its position relative to the Space Station.

4.7.6 Communications and Tracking for Tethered Spacecraft

For the option of spacecraft which are tethered to the Space Station, communications and tracking can be as for free-flyers, or they can be dependent on the Space Station. If dependent, the spacecraft would determine their location by GPS, and communications could be via conductors in the tether or short-range link to the Station. This would allow absolute or relative position determinations and direct communications.

5.0 GROUND CONTROL/SUPPORT OPERATIONS

5.1 OVERALL OPERATIONAL CONCEPT AND FACILITIES

The overall Space Station System operation control concept is depicted in Figures 5-1 and 5-2. All communication between ground and orbital elements will be direct or through a TDRSS-type element. Roles/responsibilities of the individual control facilities and their interactions are described in the paragraphs that follow.

One primary control/support center will retain strategic decisions and commands for the Space Station System, but will assign the remaining functions including commands to one or more POCCs for platforms and free-flying spacecraft. These subcontrol centers may or may not be physically located at the primary control/support center. System analysis activities may be similarly decentralized. Each subcontrol center will have both the authority and responsibility for its assigned area of activities.

Communication and data paths must exist between the primary control/support center and the subcontrol centers. POCCs will not normally require communication and data exchange with each other. The subcontrol center can communicate with the Space Station System directly including sending commands without transmitting through the primary control center. However, policy (e.g., national security/encryption, mission safety) rather than technical considerations may require all transmission and reception to pass through the primary control/support center.

5.2 SHUTTLE OPERATIONS

From the initiation of STS operations, the STS has had flight operator-developed techniques for reducing the level of STS system monitoring. The exact rate of decrease is a function of both flight phase and system maturity. This decrease is the result of the change in monitoring philosophy as fully operational systems and flight software are achieved in the operational transition

FIGURE 5-1

OPERATIONS CONCEPT - GROUND CONTROL/ SUPPORT FUNCTIONS

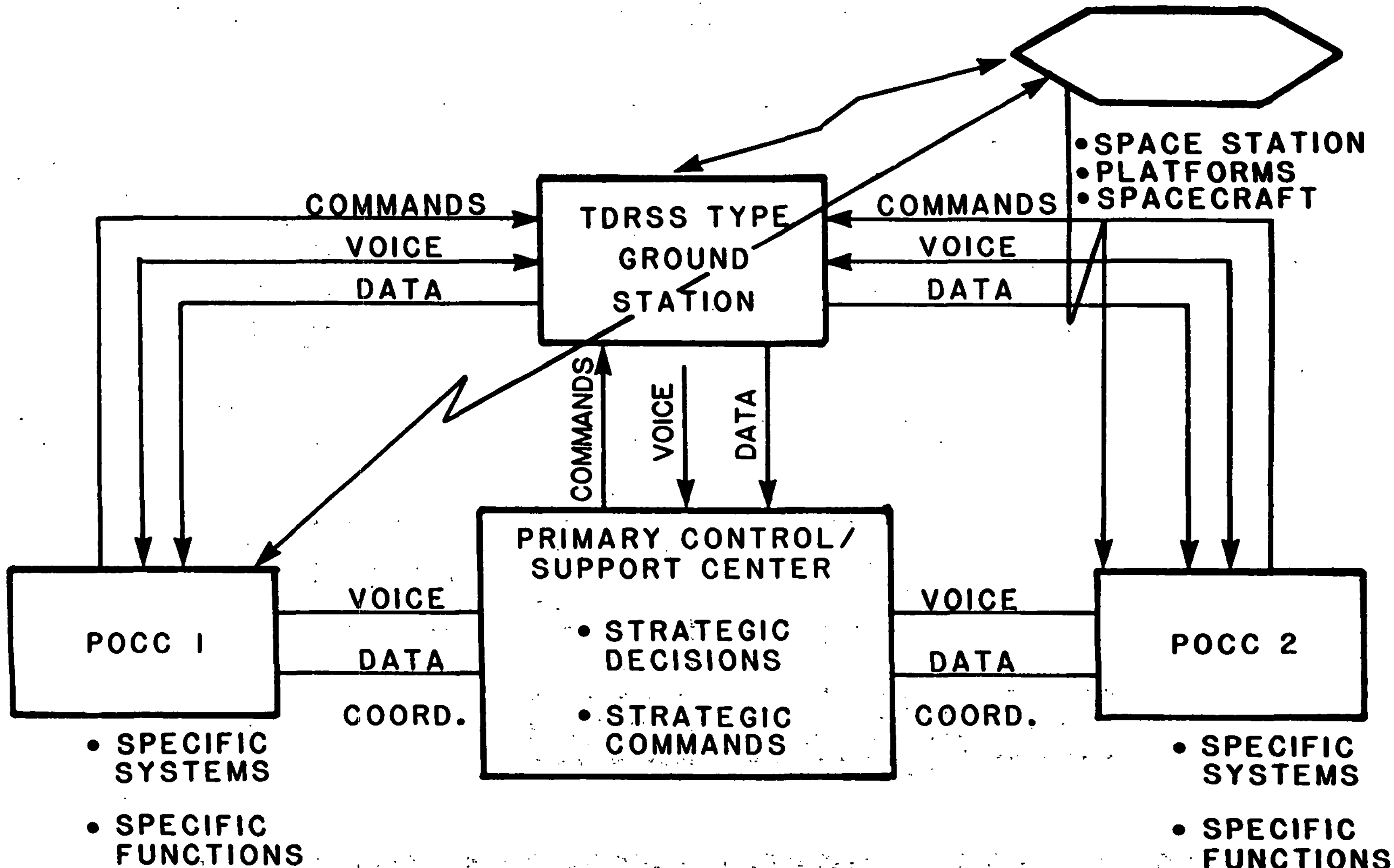
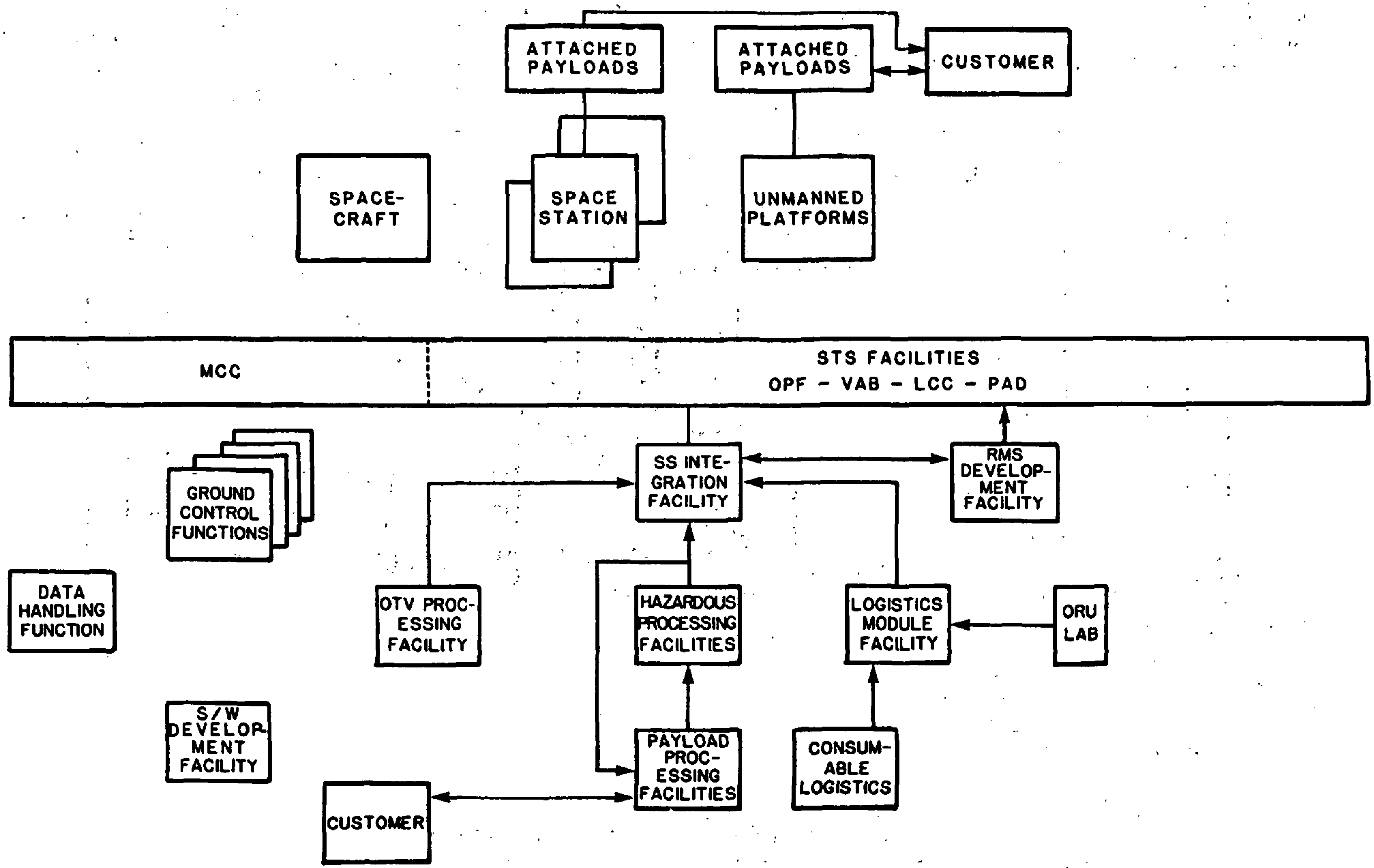


FIGURE 5-2
OPERATIONS CONCEPT - GROUND OPERATIONS



phase. At the beginning of the operational transition phase, dedicated ground teams for each vehicle will be supplanted by multi-disciplined teams as the systems mature. Within a particular STS system, the monitoring level will vary among launch, on-orbit, and landing phases.

System monitoring to augment crew capabilities will always be required during the critical flight phases (launch, landing, and rendezvous). During these phases, the crew will be occupied with flying the vehicle. The vehicle is in a dynamic state and unexpected changes must be detected and dealt with rapidly.

The Shuttle crew will have the primary responsibility for routine on-orbit monitoring of on-board systems. Ground support responsibilities are limited and will consist of a periodic review of the vehicle systems by system engineers. These engineers will use near-real-time data to evaluate overall system health and trends. Only a small amount of real-time data will be monitored continuously during on-orbit periods. This data will be used by the Flight Control Room (FCR) team for communication and data system management and Fault Summary Message monitoring. As in past programs, ground management of the communication and data systems on a 24-hour basis will relieve the crew of this routine and time-consuming task. Fault Summary Message monitoring by the FCR provides an overview of system performance relative to the flight situation and allows rapid and correct response to system problems should they occur. In the event of major contingencies on the Orbiter, additional personnel will be activated. Real-time vehicle system monitoring by the team will be initiated for major system failures that result in critical loss of redundancy or that pose a potential hazard to crew safety. In such cases, the ground provides detailed analysis of system status and capabilities to ensure crew safety.

During mature operations, trajectory monitoring will continue to be required for the critical phases of launch and entry but will be decreased substantially for the on-orbit phase. At the end of operational transition, maneuver planning (orbit shaping, rendezvous, deorbit, and entry) and ephemeris maintenance will characterize the routine trajectory ground services.

5.2.1 Pre-Launch

Mature Shuttle pre-launch flight operations will consist of countdown participation and support of any special testing related to significant changes in the flight vehicle. Normally, the Flight Control Team will begin its pre-launch support one day in advance of the countdown to have final briefings on system behavior during pre-launch preparations (KSC or VAFB) and to assemble their final real-time documentation. Actual console support will commence when the Lyndon B. Johnson Space Center (JSC) Flight Director initiates MCC operations in the countdown.

5.2.2 Launch

During the launch phase, functions of the Flight Control Team are as follows:

- To predict and identify abort situations;
- To provide vehicle configuration recommendations; and
- To compute trajectory support data as required to verify vehicle performance within nominal/operational limits or to support abort navigation.

Trajectory operations are conducted using on-board-determined state vectors (telemetered) and network tracking data. Vehicle system monitoring will depend completely on downlink telemetry data. As in previous space programs, launch aborts will be initiated only after exhausting all reasonable possibilities of achieving orbit.

5.2.3 On-Orbit Operations

During orbital flight, the Flight Control Team is responsible for providing flight-related communication management, central voice interface with the Orbiter, periodic system and trajectory monitoring, data retrieval, crew activity planning and payload support as required, and management of STS ground resources in support of payload objectives.

5.2.4 Entry Operations

Support of the entry and landing phase of the STS flights will begin with vehicle entry system preparation and monitoring. Most of this will be accomplished by the flight crew with ground support augmentation only as required.

Trajectory, meteorological, and support facility status information relative to the primary landing site will be provided to the crew by the ground on a routine basis. The same type of information will be available for the secondary landing site or contingency landing sites as required by the situation.

Following the orbit maneuver completion, the ground will be responsible for providing system monitoring and vehicle configuration management to ensure safety through the entry environment. After the Orbiter exits the communication blackout, the Flight Control team will continue to monitor both the vehicle system and trajectory performances for failure detection and will make recommendations to augment the on-board capability.

In addition, if the entry situation warrants it, a ground-controlled approach may be performed. Glidepath information and steering commands will be voiced to the crew to provide heading alignment and desired descent profile from blackout exit through final approach to the runway.

5.2.5 Rescue Operations

Upon notification of the necessity to undertake a Space Station crew rescue mission using the Orbiter, launch site personnel will first ascertain which Orbiter can be prepared for such a mission in the shortest possible time. In the worst-case situation, this has been determined to be an Orbiter already stacked in the Vehicle Assembly Building and containing a horizontally-loaded payload. The Orbiter would be destacked and rolled back to the Orbiter Processing Facility where the payload would be removed, the payload bay reconfigured, and docking hardware and rescue kits installed. In the meantime, "canned" software would be modified for this particular mission. The Orbiter would then be restacked, an integration test performed, and rollout to the pad accomplished. Launch would take place in the first available window after pad operations are completed. Ground processing time to accomplish the above is calculated to be 19 days. Worst-case delay for orbital phasing could add 2 days. Rendezvous could then be accomplished in 24 hours. Total time required is 22 days.

Other worst case rescue operations (fire, explosion, etc.) must be studied further.

5.3 SPACE STATION SYSTEM OPERATIONS

5.3.1 Initial Buildup Phases

5.3.1.1 Manned/Unmanned

During the various configurations that the Space Station will go through during its buildup, it will be manned and unmanned at times. However, the fact that it is manned or unmanned will have little affect on ground control support during the initial buildup phase.

Real-time ground support of approximately 33 flight controllers per shift will be provided to the STS and/or Space Station crew in the form of flight and system monitoring and assistance during assembly and activation of each System element. This level of support will be maintained on a continuous basis until confidence has been gained in operations in the orbital configuration. Subsequent monitoring will be limited to periodic checks. This procedure will be repeated for each new Space Station element. This periodic monitoring approach will be used for manned and unmanned Space Station operations. However, voice communication support with a manned Space Station will be on a near-continuous basis.

If the Space Station is ever unmanned, it will be deactivated to a quiescent configuration of minimum system activity requiring minimum ground operational support. Critical system control capability and appropriate payload operations will be maintained.

5.3.1.2 Orbiter Attached/Unattached

The presence of the Orbiter, attached or unattached, will have little effect on mission control support. The amount of mission control is determined by:

- Whether the Space Station has a new element; and/or
- How much confidence has been gained in the overall operation of the Space Station.

In general, ground support will be the same as that discussed in Section 5.3.1.1.

5.3.1.3 Support Functions/Allocation

New Element Activation/System Verification. The monitoring of the activation of each new Space Station element and its subsequent verification of proper system operation is the prime ground responsibility. Tasks that are the monitoring/verification responsibility of the ground include the following functions:

(1) Normal system operation/configuration;

(2) System performance evaluation/trends;

(3) Fault detection and annunciation; and

(4) Troubleshooting/malfunction analysis.

Trajectory/Flight Dynamics. The trajectory/flight dynamics function has five detailed tasks to be performed: (1) Orbital maintenance of the Space Station; (2) maneuver planning and tracking of OTV flights; (3) orbital maintenance of the unmanned platforms; (4) tracking of satellites being retrieved; and (5) Orbiter rendezvous with the Space Station or other elements. These functions should be capable of being performed by either the Space Station or the ground.

(1) Space Station Orbital Altitude Maintenance. This is a continuous task that must be performed. While the Space Station is manned, orbit determination and maneuver planning for reboost will be performed by the Space Station with the ground providing backup support as required. During the unmanned period, this function will be done by the ground.

(2) OTV Flights. The tracking and maneuver planning for launching or retrieving an OTV may require tracking that cannot be supported by the Space Station due to line-of-sight viewing constraints. However, the ground should be able to provide this capability. Therefore, responsibility should be with the ground, with the Space Station providing support within the limitations of its tracking capability.

(3) Support For Orbital Altitude Maintenance. This support of the platforms should be provided by the Space Station when possible, with assistance by the ground as required.

(4) Satellite Rendezvous. This function is similar to the OTV tracking task and should be handled in the same manner.

(5) Orbiter Rendezvous. When the Orbiter is flying, the ground will provide tracking and maneuver planning as a normal Orbiter support capability.

Communication/Data Links. The monitoring of the operation and management of the various functions of the communication/data links will be shared between the Space Station and the ground. Tasks that should be the responsibility of the on-board crew are:

(1) Antenna management;

(2) Command/control of OMV and OTV; and

(3) Tracking external vehicles (proximity).

Tasks that are the responsibility of the ground are:

(1) Network scheduling;

(2) Recorder management (expert systems/advanced technology may reduce/reverse this requirement);

(3) Tracking external vehicles (not in Space Station view); and

(4) Command/control of OTV or OMV (not in Space Station view).

5.3.2 Operational Phase

5.3.2.1 Manned/Unmanned

During the operational phase, confidence will have been achieved in the ability of the Space Station systems to operate in an autonomous fashion with minimum support of approximately seven ground support personnel per shift on the ground when the Space Station is manned.

If the Space Station is ever unmanned, it will be placed in a quiescent configuration with minimum system activity requiring minimum ground operational support. Control of critical systems and payload operations will be maintained.

5.3.2.2 Support Functions/Allocation

New Element Activation/System Verification. Functions for activation and verification of the systems in a new element during the operational phase will be allocated in the same manner as for the initial buildup phase. (Refer to Section 5.3.1.3.)

Trajectory/Flight Dynamics. Functions for trajectory/flight dynamics during the operational phase will be allocated in the same manner as for the initial buildup phase. (Refer to Section 5.3.1.3.) Ground systems shall maintain ephemerides of all known Earth-orbiting craft and shall take appropriate action to ensure safe minimum separations with respect to the Space Station during all phases from launch on.

Communication/Data Links. Functions for the communication/data links during the operational phase will be allocated in the same manner as for the initial buildup phase. (Refer to Section 5.3.1.3.)

5.3.2.3 Planning

Crew Rotation. Planning and scheduling for rotation of the flight crews depend on factors such as level of training and type of Space Station mission to be performed during the next crew's tour of duty. The fact that training will be provided to some of the crew by the Space Station itself should also be considered. Therefore, the ground appears to be the only possibility with access to all the data necessary to perform the task.

Resupply. Planning of items needed for resupply and determination of when the needs will arise will be a coordinated effort between the Space Station and the ground. Since the ground will be aware of the overall picture of long-range activities for the Space Station System and items required to support those activities, it should be prime for this planning phase and should be supported by the Space Station System as required from the standpoint of consumables and of subsystems that need replacement ORUs, etc.

Structure Delivery/Construction. Planning for scheduling delivery of structures and for their assembly must fit into the overall Space Station System operational plan and Orbiter traffic model which are developed by the ground. Therefore, the ground should plan these activities.

Satellite Delivery/Retrieval/Servicing. This planning task is based either on the schedule to place a new satellite in orbit or on the need to perform service(s) to an existing satellite in orbit.

This information would be obtained from the agency or organization that was responsible for the satellite and would then be integrated into the Shuttle launch schedule and Space Station System operational plan. This is a task that must be performed by the ground since it must integrate requirements from a number of different sources.

Daily Housekeeping Chores. These are tasks that are routine and must be done daily or on a periodic basis. Some examples are galley duty, trash removal, general cleaning, and inventory of various consumables. The overall requirement for planning these activities on a day-to-day basis is best done by the flight crew since the placement in the schedule of daily activities may not be critical and can be done as blocks of time become available.

Maintenance And Repair Schedules. This task will depend on subsystem design, operating requirements, and maintenance capability. Planning these activities will be on a routine basis for some subsystem maintenance such as cleaning or replacing filters and repair as required. In some cases, spare parts will have to be delivered by the Orbiter; therefore, the ground and the flight crew will have a prime role in planning this task.

Health Maintenance. This will be a routine task for each crew member and can best be handled on the Space Station based on the individual's work schedule.

Mission/Activity Planning.

The capability to conduct near-term activity planning shall be provided on board the Space Station, and long-term planning shall be accomplished by the ground.

- Near-Term Planning - Planning of daily activities for which information is available on-board including replanning when circumstances have made previous planning unworkable. Some examples are: experiments, general housekeeping tasks, subsystem status checks, failures, payload mission planning, preventive maintenance, and consumable inventory.
- Long-Term Planning - Planning that requires the consideration and integration of numerous facts and requirements to which the flight crew may not have access or that can be accomplished more efficiently on the ground.

5.4 PAYLOAD OPERATIONS

The Space Station operational approach is to divide functions into groups of logical management and control responsibilities that support autonomous operations, allow coordination and integration when required, and provide key control functions to be payload-independent. Primary allocation of functions is discipline-oriented and provides independent control of each of the orbital elements. There is an additional allocation of responsibilities that provides interdependent operation during orbital servicing or payload changeout.

Payload ground control will provide autonomous science operations. Customers are able to function apart from the Space Station System while providing required payload planning inputs. Functional separation of control provides the desired separation of science data from the Space Station or platform data.

Payload checkout and performance monitoring are conducted by both on-board and by the ground. Science payload mission time-line planning and the analysis to reconfigure the payloads is conducted by the ground, as is a limited amount of science data processing.

6.0 PRE-LAUNCH GROUND OPERATIONS

6.1 GENERAL

The concept for pre-launch ground operations necessary to support Space Station System integration, checkout, and launch for both the initial buildup phase and operational phase is discussed in this section. Geographical locations for these activities are not yet defined although some will obviously take place at the launch site. Included in this discussion are Space Station element verification, interface verification, interaction with the STS and ground systems, element refurbishment and reflight, payload ground operations, and ground support of on-orbit operations. Pre-launch ground operations software has not been specifically included but will be added in the future. The primary objective of the Space Station System pre-launch ground operations process is to assure that the integrated flight and ground systems satisfy the applicable verification requirements. This objective will be accomplished by demonstrating that the performance of the combined Space Station System subsystems, elements, payloads, and ground support equipment (GSE) meet established requirements and that the related interfaces are compatible and functional. Where possible, existing facilities and GSE will be used to support these operations. Final configuration of Space Station System elements and payloads will determine the extent of this utilization.

6.2 INITIAL BUILDUP PHASE

Initial buildup phase is defined as all integration, checkout, launch, and on-orbit assembly/activation/verification activities required to deliver on-orbit the initial complement of Space Station System elements.

Processing the initial flight elements will be achieved by assembling and testing the elements; approximating the operations to be performed in space. Prior to beginning flight element processing, operation of all facility services and GSE will be verified. Element processing will begin with the receipt of a fully assembled flight article, except for mission dependent items and consumables. The elements will be off-loaded and transferred to the Space Station checkout facility, unpacked and inspected, installed in a test stand, and stand-alone, power-off operations accomplished. These operations will include keel installations, alignment and clearance checks, fluid system leak tests, berthing and docking mechanical interface tests, a module pressure decay test, and connection of GSE and simulators. The solar array and thermal radiator will be processed alone and off line from the utility module primary structure.

Since the utility module will be launched alone and operated as a single element in space, its ground checkout will consist of a series of detailed subsystem tests followed by an on-orbit activation test to simulate the sequence of initial activities to be performed when the element is first placed in orbit. This test will be followed by an Orbiter-to-Space-Station-element interface test to verify the functions that must be supplied by the Orbiter to sustain or verify the health of the Space Station element during the launch and delivery into space. During these utility module operations, the MBA stand-alone, power-off functions are performed.

The utility module will then be mated to the MBA and the detailed subsystems of this additional element will be checked out using the functional interfaces supplied by the utility module with simulators for the thermal radiator, solar array, and power storage units. The power-off operations of the habitat module will be performed in parallel with the MBA subsystem testing.

The habitat module (HM) will be mated to the checked-out MBA and the HM subsystems will be verified. This will be followed by an on-orbit activation test of the MBA-HM-utility module combination to simulate the post-berthing tests of the second Space Station cargo to be delivered by a single STS launch. The resupply module power-off preparations will be sequenced to mate with the MBA at the conclusion of this test.

The resupply module subsystem tests will be performed using the Space Station elements previously mated and verified. Again, an on-orbit activation test of the resupply module will follow to simulate the post-delivery of the third Space Station launch. Power-off preparations of the first laboratory module will be sequenced to mate with the assembled and tested Space Station elements.

Subsystem checkout of the first laboratory module will be performed while the pre-mate, power-off operations are being performed on the second laboratory module. Previously checked-out individual racks of experiments will be installed in the first laboratory module and a series of experiment rack interface tests will be performed.

At the conclusion of these tests, an on-orbit activation sequence test of the first laboratory module will be performed. During these tests, the second laboratory module will be mated to the MBA and its subsystem tests begun. Experiment racks will be installed and verified in the second laboratory module and an on-orbit activation test performed.

Following the final assembly and test of the initial six Space Station elements, an all-element integrated test will be performed. Operations such as a total Space Station pressure decay test, EMC, POCC, and crew familiarization and training could be performed. After this test, the elements will be demated in order to prepare them for launch. Any Space Station System AFD equipment will be transferred to the OPF for installation in the Orbiter.

The utility module will be mated to its solar array and thermal radiator and these interfaces will be verified. All non-hazardous, non-perishable consumables will be loaded and a closeout inspection will be performed in preparation for moving the element to the Orbiter. The weight and center of gravity (CG) will be determined as the element is hoisted into the transporter canister. The loaded canister will be rotated to the vertical position and moved to the Rotating Service Structure at the launch pad for hoisting into the Payload Changeout Room.

The utility module will be installed in the Orbiter and its fluid and electrical interfaces mated, and a cargo-to-Orbiter interface test performed. These functional tests will be followed by the fluid and gas loading, hazardous material and equipment installation, and a final stowage of any perishable materials. A final cargo closeout inspection, Orbiter closeout, and countdown will complete the processing for the first Space Station launch of the resource module.

Since the MBA and habitat module may be launched by a single Orbiter, these elements could be prepared for launch without disassembling them to minimize the handling and re-verification risk after ground processing. These elements would be processed through the same sequence as the utility module in preparation for launch.

The weight of a fully loaded resupply module requires it to be launched and delivered without another Space Station element. It will be prepared for launch as the third Space Station cargo.

Both laboratory modules may be delivered by a single Orbiter depending on Lab Module design and the Orbiter envelope; however, they will be berthed to the MBA as single elements and they will, therefore, be processed as a two-element cargo for the fourth Space Station launch.

This completes the processing of the initial six Space Station elements. This overall processing flow is depicted in Figure 6-1.

Figure 6-2 is a top-level overview of the Space Station facility and IOC flow.

6.3 OPERATIONAL PHASE

The operational phase includes activities required subsequent to the initial buildup phase. The operational phase will include, but is not limited to, expansion of the Space Station System in the form of platforms, an OTV, an OMV, additional modules/elements (logistics, laboratory, etc.), processing of returnable modules, and processing of payloads.

6.3.1 Element Integration and Checkout

Element integration and checkout activities during the operational phase will be essential identical to those of the initial buildup phase. Development and acceptance testing will be accomplished. Major buildup, integration, and checkout activities will be performed.

FIGURE 6-1
IOC SPACE STATION FLIGHT ELEMENT PROCESSING

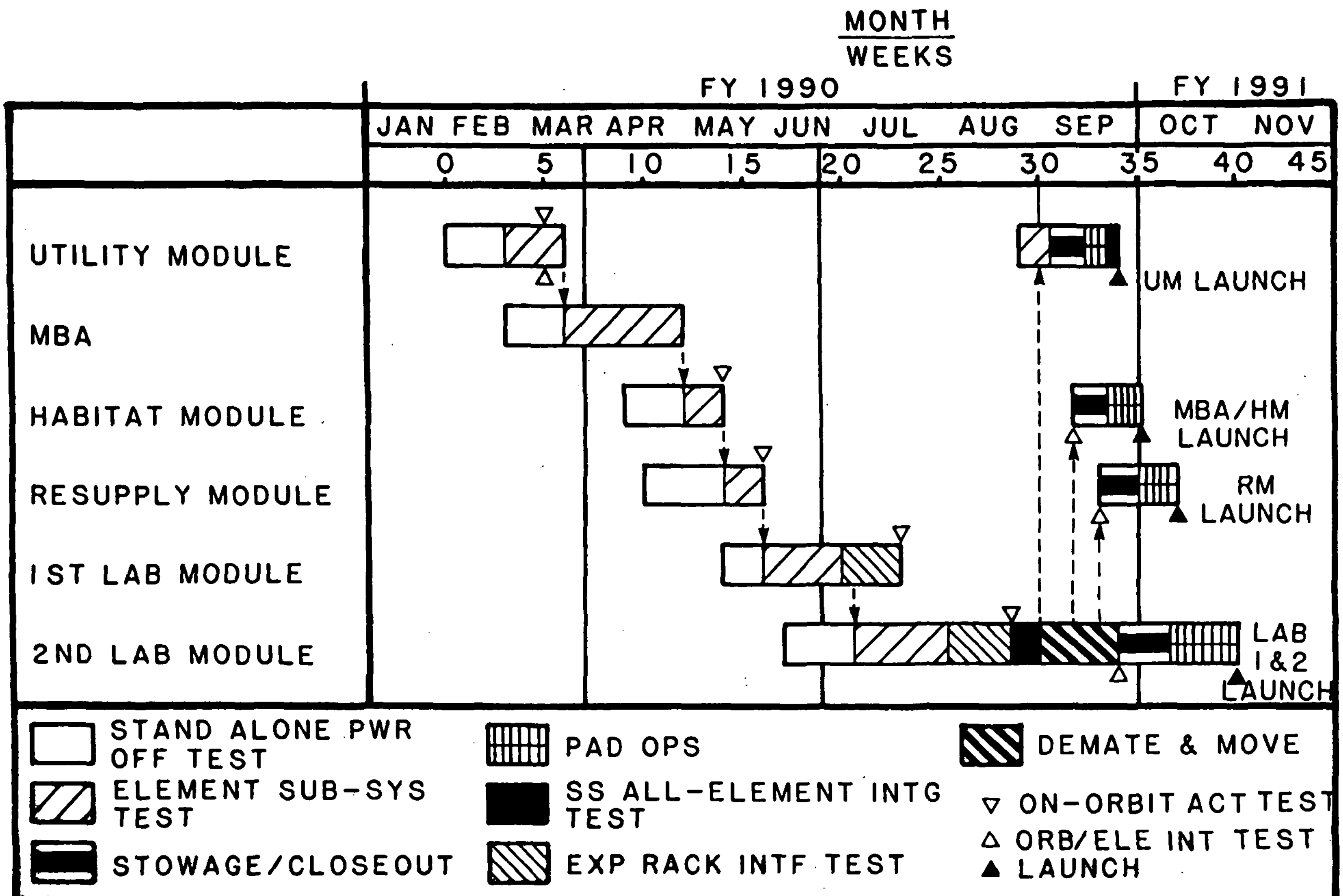
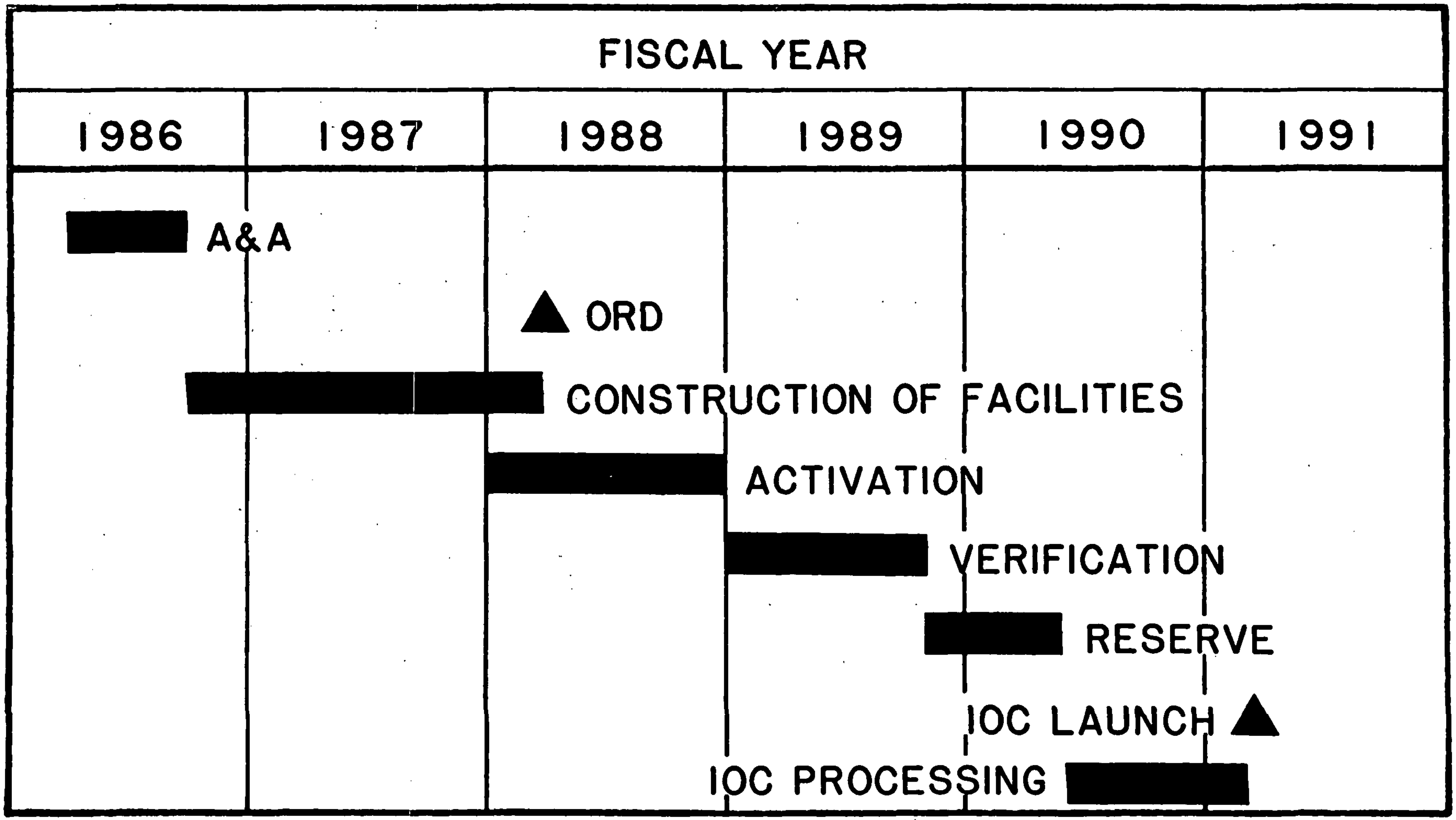


FIGURE 6-2

OVERALL SPACE STATION FACILITY AND IOC FLOW



6.3.2 Space Station System Integration and Checkout

These activities will also be accomplished in the same manner as those of the initial buildup phase, providing assurance that the components, subsystems, and system elements have been assembled into the desired configuration and verifying/reverifying compatibility between the constituents of the assembly. In the operational phase, the ground control center, on-orbit system, and TDRS will be used during ground checkout to verify end-to-end system compatibility.

6.3.3 Space Transportation System Operations

Upon completion of Orbiter interface verification, the integrated Space Station assemblies will be delivered in a launch-ready configuration for installation in the Orbiter. As in the initial buildup phase, integrated testing with the Orbiter will be minimal, limited to a verification that the interfaces are compatible and functional. STS pre-launch and launch activities are discussed in Sections 5.2.1 and 5.2.2, respectively.

6.3.4 Returnable Elements

Elements designed to be returned to Earth and reused will be brought back from orbit by the Orbiter. Operations for landings of Space Station System elements at sites other than KSC have yet to be analyzed but will be studied. Following landing and safing operations, the element(s) will be removed from the Orbiter in the OPF and transported to the integration facility. Required deintegration, maintenance, and refurbishment activities will be accomplished. Reverification will be performed as required. These elements will then be placed in storage until they are required for reuse. Returnable elements will include logistics modules, payload/laboratory modules, and pallets and spacecraft/payloads. The most common of these elements will be the resupply module, with a typical cycling between the ground and orbit every 90 days.

6.4 PAYLOAD OPERATIONS

Operations are required for the processing of payloads, upper stages, and any other assembly that is not part of the basic complement of Space Station elements but that will be tended or further processed through the Space Station. The total system operation, including ground and space operations will be tailored to avoid introducing unwarranted requirements on payloads. Included are foreign, domestic, commercial, and government payloads.

6.4.1 Payload Integration and Checkout

Before integrated testing with the Space Station System, the responsible payload personnel will assemble, calibrate, checkout, and validate their payload, culminating in a certification that the payload meets all safety and interface requirements. Services will be provided by the host site owner as negotiated.

6.4.2 Payload/Space Station Integration and Checkout

Payload/Space Station integration and checkout activities will be conducted by the Launch Center with the payload contractor to assure compatibility between the constituents of the launch assembly. Functional verification and compatibility of the payload/Space Station System with support systems (including ground control, TDRS, and STS) will be demonstrated.

6.4.3 Space Transportation System Operations

Upon completion of Orbiter interface verification, the integrated Space Station/payload assembly will be delivered in a launch-ready configuration for installation in the Orbiter. Integrated testing with the Orbiter will be minimal, limited to a verification that the interfaces are compatible and functional. STS pre-launch and launch activities are discussed in Sections 5.2.1 and 5.2.2, respectively.

6.4.4 National Security Payloads

These payloads may be attached or free-flying spacecraft and will be developed, tested, and flown by or in support of the Department of Defense (DOD). Ground operations of these payloads will be conducted under secure conditions as required. The DOD will provide certification that these payloads meet safety and interface requirements of the Space Station System and the Orbiter.

6.5 GROUND SUPPORT TO SPACE STATION ELEMENTS

6.5.1 Verification Program

A verification program will be developed to support both the initial and the operational phases of the Space Station System program. Initially, this program would provide the capability to verify the following: (1) Facility/GSE operations and procedures; (2) application software and flight procedure development; and (3) initial element integration checkout. In the Space Station System operational phase, verification presents a unique challenge since the initial elements will be on-orbit before some of the follow-on elements and payloads are fabricated, precluding any possibility of a physical interface test with the actual flight hardware. Additionally, modification kits will be developed to meet new requirements, correct problems, and improve operations. As time goes on, systems will be upgraded to keep pace with advancing technology. Other new interfaces and procedures will be verified to ensure their proper operation on-orbit and to demonstrate end-to-end system operability and maintainability. Implementation approaches to this verification program cover a wide range, the extremes being a total computer/software simulation of the flight systems and a total hardware/software duplication of the flight system. The optimum approach lies somewhere between and studies are continuing in an effort to make that determination.

6.5.2 Ground Support Equipment

GSE will be designed and developed by the responsible Center to support all Space Station element transportation, handling, assembly, and checkout requirements.

6.5.3 Support to Ground Operations

Logistics. Support will be provided to plan and schedule integrated logistics operations to facilitate the on-going activities of the Space Station System and its payloads. Activities will include resupply of consumables, maintenance data collection and analysis, provisioning of spare parts, repair of failed components, and inventory control.

Medical. Support will be provided to assure that transient, on-orbit personnel meet minimal medical requirements and that baseline medical records are complete.

Configuration Management. Support will be provided to assure Space Station System configuration, identification, control, and status.

Safety, Reliability, and Quality Assurance (SR&QA). Support will be provided to assure compliance with SR&QA requirements in all aspects of Space Station operations and support.

Life Science. Support will be provided for handling biological life to be taken to the Space Station.

6.6 POST-LAUNCH ABORTS AND CONTINGENCY LANDING SITE (CLS)

Support for operations resulting from a post-launch abort or contingency landing will be jointly determined by the STS, Space Station program, and payload owner.

7.0 TRAINING

The crew and ground controllers must be prepared for a wide range of tasks; however, the training cost shall be minimized for the following reasons:

(1) Timely involvement of crew/ground controllers will be included in the design and development phases of the Space Station System. This will provide operational personnel with an in-depth knowledge of the Space Station System design, system interaction, and operational limitations.

(2) All areas of the training program will rely heavily on the uses of workbooks, classroom presentations, and video tapes. Crew/controllers will participate in the development of these materials whenever practical.

(3) On-the-job training (OJT) will be heavily relied upon after Space Station System buildup has been achieved.

(4) Crew machine-designated interfaces for flight and training shall be based on standard work stations with features such as color graphics, call up of pre-coded routine procedures (and other S/W switches), and help and tutorial software.

7.1 BASIC TRAINING FOR CREW AND GROUND CONTROLLERS

The crew and ground controllers require a basic knowledge of space operations, orbital mechanics, space power systems, space environment, physiology in space, etc. A formal training program will be developed to fill this need.

7.2 CREW TRAINING

Due to the fact that the initial crews will be small in number, skill cross-training will be required; however, as the number of crew persons per crew increases, more specialization may occur.

7.2.1 Routine Tasks

The crew will be trained to perform daily housekeeping tasks such as meal preparation, hygiene, and cleaning before flight. Training will be accomplished through use of a one-g facility. Training facilities should use working mechanisms and physical representations as close to flight-like hardware as possible in a one-g environment.

7.2.2 System Monitoring And Maintenance

The crew will be trained to monitor, operate, and maintain Space Station Systems such as environmental control, on-board computers, and electrical power.

System trainers will be used to provide training that exercises an interactive interface between the crew and the simulated systems. Normal operations, such as in-flight maintenance, will be emphasized. Flight hardware and software will not be required, and most "normal response" training will be replaced by OJT after Space Station System buildup is accomplished.

7.2.3 System Emergencies

The crew will be trained to respond to problems where crew reaction time is critical to the safety of the crew and/or hardware (e.g., hole in cabin). Crew maintenance procedures and proficiency will be developed and maintained. System trainers will be used to practice recognition and safety procedures before flight and an interactive training device will be provided on-board for proficiency maintenance.

7.2.4 Non-Routine Servicing and Maintenance

Training will be provided before flight on operations necessary for maintenance and servicing activities that will occur on an irregular basis. Prior to flight, system trainers will be used with operations where hand-to-eye coordination is a factor. Depending upon task complexity and frequency of occurrence, consideration will be given to installing an interactive training device on-board that would be used to maintain crew proficiency.

7.2.5 Construction/Assembly And Development Of Platforms

A significant portion of crew training for construction and assembly will be acquired via plant visits and "hands-on" activities utilizing actual hardware (pre-flight). NASA facilities such as the neutral bouyancy facility at MSFC, the Manipulator Development Facility, the Weightless Environment Training Facility (WETF), and the altitude chambers will be utilized, when necessary, to provide crew training. Formal on-board training is not anticipated.

7.2.6 Manned Maneuvering Unit And Orbital Maneuvering Vehicle Training

The crew will be trained to use the MMU/OMV to provide access to the co-orbiting elements of the System, as well as other assigned tasks.

A system trainer will be used to learn normal and contingency operations before flight. During flight, a computer-aided instruction device will be used as a memory refresher for critical problems/actions. Depending upon the requirement for hand-to-eye coordination, consideration will be given to providing an interactive training capability on-board.

7.2.7 Orbital Transfer Vehicle Training

If the OTV is space-based, the crew will be trained to deploy, retrieve, service, test, and perform propellant loading on the OTV before flight. Consideration will be given to providing an interactive training capability on-board.

7.2.8 Extravehicular Activity Training

Crews will be provided generic EVA training for identified contingencies and flight-specific training for scheduled EVAs (i.e., satellite servicing and assembly).

7.2.9 Training In Support Of Customer Goals

Crew training in the area of customer hardware/goals is the responsibility of NASA and the customer. Space Station training hardware/personnel will be available at cost to the customer.

7.2.10 Medical Training

All crew members shall have at least first aid/CPR training. One crew member shall have extensive medical training equivalent to that of an Emergency Medical Technician and an anesthetist/surgical assistant. One other crew member shall have at least 100 hours of medical training, with a demonstrated proficiency of (TBD).

7.2.11 Mission Planning/Timeline Generation

Training for near-term planning in support of the operation of experiments and payloads will be provided.

7.3 GROUND CONTROLLER TRAINING

Space Station System ground controllers must be prepared for a very active role during the Space Station buildup phase; however, the ground role becomes one of routine periodic monitoring plus "on call support" after buildup has been accomplished.

7.3.1 Routine Tasks

Ground controllers will be trained to operate ground systems, retrieve and manipulate data, etc. Training will be accomplished through the use of the actual ground system.

7.3.2 System Evaluation/Response Training During Buildup

Controllers must be prepared to evaluate a Space Station System upon initial placement of each module in orbit. This evaluation is time-critical to assure that problems can be recognized and a response initiated (if appropriate) before the Shuttle departs.

System trainers will be used to simulate a real-time environment for each of the ground controllers at his/her ground-based work station. System and trajectory modeling will be limited to critical elements where ground support can influence the action taken.

7.3.3 Daily System Evaluation/Response After Space Station System Buildup

During flight, ground controllers will perform daily data evaluations to pinpoint potential problems in a timely manner so that the impact of these problems can be minimized or avoided.

Simulator systems will not be required to maintain controller proficiency in this area. Normal operations will be sufficient to maintain proficiency.

7.3.4 On Call Evaluation/Response After Space Station System Buildup

Ground controllers will be "on call" to support the evaluation and resolution of problems by the on-board system/crew. When this occurs, controllers will probably use the real-time data system, developed for Space Station System buildup, and the in-place system for daily evaluation.

System trainers will be used on a regular basis to maintain proficiency in this area, and scheduling will utilize a "fire drill" approach in addition to regularly-scheduled proficiency runs. Most of this training will be provided on an individual basis with occasional exercises that involve the entire controller team. Ground personnel will support the exercises from a set of "networked" system trainers.

7.3.5 Training In Support Of Customer Goals

Ground controller training (i.e., commands and data retrieval) in support of the customer is the responsibility of NASA and the customer.

7.4 CREW/GROUND CONTROLLER CROSS-TRAINING

Crews and ground controllers will be trained to perform their specifically assigned tasks independently; however, cross-training at a basic level will be provided to assure smooth team operation. More specifically, ground controllers will receive a subset of the training described in Section 7.2, and the crew will receive some of the training described in Section 7.3.

7.5 INTEGRATED TRAINING

A requirement exists to "integrate" the crew and ground controllers in training exercises before flight. To assure that they function efficiently as a team. Normal and abnormal operations will be practiced using system trainers. Customer operations may also require they be integrated.

7.6 CUSTOMER TRAINING

Customers will be trained in preparation for their interface with the Space Station System whether it is from the ground or on-board. In all cases, simple and standard interfaces will facilitate customer training.

7.6.1 On-Board

As a crew member, the customer will be required to know general Space Station operation and capabilities, communication protocol, hardware and software interfaces with his experiment, and Space Station emergency procedures. Training will be accomplished on the ground and on-the-job. Training in the operation of the customer's experiment will be provided by NASA and the customer.

7.6.2 Ground Operations

Ground operation of a Space Station System experiment may require the customer to be trained in ground communication, command protocol, procedures, and data manipulation in order to maximize the science return.

Simple interfaces and data systems transparency will permit training to take place at the customer's facility/institution or at a control center.

7.7 QUALITY ASSURANCE TRAINING

A training program is required for Space Station personnel assigned to perform on-orbit quality assurance functions. This includes training for the Space Station crew and technicians/scientists (whether NASA, DOD, or customer personnel) assigned to perform inspections/verifications relative to fabrication, assembly, test, repair, non-destructive evaluation, modifications, calibrations, or any other function that would normally be performed by quality assurance personnel if the function was performed on the ground.

8.0 GROUND-BASED FACILITIES AND FACILITY CONCEPTS

8.1 GENERAL

A functionally effective combination of existing and used STS-developed facilities and new Space Station System unique facilities will be required during the Space Station program. NASA, payload customers, and Space Station contractors will develop an Integrated Facility Utilization plan early in the program. These facilities may also be useful during design/development for design verification. Requirements for new facilities will be based, in part, on the continuing needs and configurations of the STS and on results of cost analyses relative to modification of old versus construction of new.

With the exception of existing facilities, geographic locations for conceptual facilities are not yet established.

8.2 SPACE TRANSPORTATION SYSTEM FACILITIES

Existing facilities that will continue to be required for ground operations of the Space Station elements/payloads are identified as follows.

Orbiter Processing Facility (OPF): The OPF provides facility support to Space Station elements/payloads, before launch and after landing (if applicable).

Launch Control Center (LCC): The LCC provides operator control of all activities associated with Space Station element/payload and Shuttle checkout after Orbiter/cargo integration.

Vehicle Assembly Building (VAB): Space Station element/payload functional activities will not be performed in the VAB. Rotation of horizontally-processed elements may occur in the VAB in preparation for vertical installation at the pad.

Launch Pad: The launch pad provides facility support to Space Station elements/payloads before launch.

Shuttle Landing Facility (SLF): The SLF provides ground support to Space Station/payloads after Orbiter landing.

8.3 SPACE STATION ELEMENT/PAYLOAD FACILITIES

Conceptual new facilities or potential modified existing facilities that have been identified for ground operations of the Space Station and Space Station System payloads are described below.

Space Station System Integration Facility: This facility will be provided to process and integrate Space Station elements. Maximum use will be made of existing facilities. The facility will provide certain capabilities such as environmental control for hardware cleanliness, floor space and sources to accommodate Space Station System flight hardware, and the GSE necessary to perform integration and checkout activities. This facility will also support the integration and checkout of the combined initial operational capability (IOC) Space Station System elements. This facility will provide floor space and services to meet hardware requirements.

Resupply Module Facility: The resupply module will cycle between the ground and orbit approximately every 90 days. A dedicated facility or area will be provided for module refurbishment, maintenance, and overall preparation for its resupply mission. This facility must accommodate a minimum of three resupply modules and provide the capability to handle all commodities carried by the module to and from the orbiting Space Station. It will also provide the capability to process a variety of ORUs for the Space Station System and provide sufficient warehousing capability to support mission requirements.

Payload Processing Facilities: These facilities will provide the capability to process payloads in vertical and horizontal modes. Existing facilities will be used when possible. The capability to secure an area for the processing of a national security payload will be provided. Environment will be controlled to meet temperature, humidity, and cleanliness requirements of the hardware. Floor space and services will be provided to accommodate payload flight hardware and the GSE necessary to perform integration and checkout activities.

Hazardous Processing Facility: Space Station elements and payloads containing systems that are considered hazardous to service, activate, or checkout will be required to accomplish these activities in a Hazardous Processing Facility. This facility will provide safe handling of hazardous materials including hypergolics and cryogenics. Upon completion of hazardous operations, the Space Station element or payload will be delivered to the launch pad for installation into the Orbiter.

Software Development Facilities: These facilities will provide the capability to define, design, code, verify, validate, integrate, and document the software required for the operation of the Space Station System and its ground-based support systems.

Space Station System Ground Control And Monitor Facility: This facility is the prime ground element responsible for controlling and planning the orbital Space Station System ongoing missions. The facility will provide the necessary control and monitoring of the Space Station System during deployment, activation, and the initial operational phase. The facility will also be capable of controlling and monitoring the Space Station in an unmanned/untended mode during periods of planned non-occupancy and of providing the prime control of co-orbiting platforms in their initial phase. Trajectory and flight dynamics analysis to support the complete projected operation of the Space Station System will be performed within the facility. Other capabilities will be the containment of the existing flight planning systems that assist in the development of crew activities and monitoring of new element operations in parallel with the flight crew.

Manipulator Facility: A manipulator is planned as the major tool to maneuver elements from the Orbiter to the Space Station for the life of the Space Station. This facility will be required to develop future generations of manipulator capabilities and interfaces with Space Station elements and payloads.

Orbital Transfer Vehicle Processing Facility: This facility will be used to process, service, and prepare the OTVs for launch and transfer to the Space Station. The facility will be capable of processing the hazardous systems on the OTV and will contain the same servicing and checkout equipment that is on-board the Space Station. An existing facility could be used with modifications for servicing and checkout.

Platform Control Function: This function is the ground element for platform-related activity in conjunction with Space Station System ground control. A separate ground control facility may be required for the polar platform.

Mission Control Center (STS): The existing MCC will continue as the primary interface with the Orbiter. Modifications will be required to accommodate Space Station communications during interactions between the Orbiter and Space Station.

Payload Operation Control Centers (POCC): POCC facilities operated by the customers will control the customer's respective payloads and receive the data produced by the mission.

One-g Trainer: The one-g trainer will be a full-scale mockup of each manned element equipped with operational waste management, lighting, galley systems, sleep stations, EVA suit stations, and all support equipment. This trainer may also be used for engineering development. It should be kept in the same configuration as the on-orbit Space Station for reference.

Proximity Operation Trainer (POT): The POT will provide part-task training in station-keeping, grappling of structures/satellites/vehicles, and assembly activities. The trainer will consist of a full-scale, high fidelity Space Station command/control crew station, controls and displays, and a visual system. Consideration will be given to linking the POT with the existing Shuttle Mission Simulator (SMS) to simulate Orbital arrival and departure. The POT also will be used to train for traffic control around the Space Station. A full mockup of the Space Station elements will be required.

<u>Weightless Training Facilities</u>: The weightless environment training facility, neutral bouyancy simulator, KC-135, Orbiter, etc. will provide part-task and full-task training in the dynamics of body motion during the performance of planned crew activities under weightless conditions.

<u>Altitude Chambers</u>: Altitude chambers will provide simulated flight environment pressures during full-task training in the operation of EVA support systems for nominal and off-nominal procedures.

<u>Space Station System Trainer (SSST)</u>: System training facilities will be required to provide adequate training for Space Station crews and ground controllers during Space Station System buildup and will be capable of efficiently maintaining crew/controller proficiency following buildup. It is envisioned that the SSST will consist of medium fidelity, Space Station module simulators using flight-type hardware and actual flight software. It will provide approximate module interior geometry with fully representative control panels and interactive controls and displays. However, use of flight hardware will be avoided to reduce cost.

9.0 OPERATION STUDIES

9.1 SUMMARY OF OPERATION STUDIES

In order to provide an in-depth background for the operational principles discussed in this document, the Operations Working Group initiated a series of studies in November 1982 to conduct operational methodology trades and to document operational philosophy applicable to the conceptualized Space Station System. These studies included contributions and participation of all NASA Centers and were reviewed in depth by the Operations Working Group to arrive at the best possible Agency consensus. The Operations Studies were divided into six groups with a group leader assigned to manage each of the groups. These study groups and leaders were:

(1) Maintainability: J. Lusk, MSFC

(2) Automation: J. Lusk, MSFC

(3) Operational Approach: H. Loden, JSC

(4) Customer Interfaces: T. Goldsmith, GSFC

(5) Safety: H. Loden, JSC

(6) Pre-Launch Processing: J. Oertel, KSC

A complete listing of the individual studies and leads, study plans, and participants are contained in Appendix B, Space Station Operations Study Plans, dated May 1, 1983 (published separately).

9.2 SECOND LEVEL WHITE PAPERS

The Operations Studies detailed reports are documented in Second Level White Papers prepared by the individual study leads and are included as Appendix C (published separately).

9.3 FIRST LEVEL WHITE PAPERS

The Operations Studies summary reports of the six major groupings are documented in First Level White Papers prepared by the groups and are included as Appendix D (published separately).

10.0 SUMMARY OF OPERATIONAL REQUIREMENTS

The requirements summarized in this section are applicable only to the Space Station System.

These requirements do not apply to nor are intended to constrain the operations and design of privately owned and operated flight elements/payloads that use or interface with the Space Station System except those requirements that deal with safety or interface compatibility. The safety and interface compatibility requirements apply to all users of the Space Station System.

The requirements for the Space Station System operations are defined in this section for the following operational categories: (1) overall operations; (2) safety; (3) medical; (4) customer operations; (5) automation; (6) maintainability/maintenance for hardware and software; (7) habitability; (8) operational security; and (9) operational quality assurance. Each category is discussed in detail.

10.1 OVERALL OPERATIONS

The overall operations of the Space Station System are divided into the following sub-categories: (1) pre-launch processing and launch operations; (2) on-orbit flight operations; (3) ground control and support operations; and (4) logistics operations. The operational requirements governing the ground rules for and constraints to these sub-categories are given in the following paragraphs.

10.1.1 Pre-launch Processing and Launch Operations

Ground operations necessary to support Space Station System integration and checkout during both the initial establishment of an on-orbit System and the operational era include element verification, interface verification, interaction with the Space Transportation System (STS) and ground systems, element refurbishment and reflight, payload ground operations, and ground support of on-orbit operations. The primary objective of the Space Station System ground operation verification process is to assure that the integrated flight and ground systems satisfy the applicable requirements. This objective shall be accomplished by demonstrating that the performance of the combined Space Station System subsystems, elements, payloads, and ground support equipment (GSE) meet established requirements, and that related interfaces are compatible and functional. The result of each complete pre-launch ground operations process shall be a launch-ready assembly of components, subsystems, and System elements in the desired configuration. Subsequent to the initial establishment of an on-orbit System, interface verification will present a unique operational challenge in that the System will be on orbit before some elements and payloads are fabricated. This will preclude any possibility of a physical interface ground integration test. A capability shall be developed to verify new interfaces and procedures to ensure their proper operation on orbit and to demonstrate end-to-end system operability and maintainability. GSE and facility capabilities compatible and consistent with applicable safety practices and documentation shall be provided to support Space Station element handling, assembly, and checkout requirements.

The following ground operation requirements are established:

(a) Pre-launch operations shall provide for servicing/deservicing of all elements/payloads and for verification that systems are launch ready, including form, fit, and function verification testing to minimize on-orbit incompatibilities. Payload-to-Station interface verification testing will be minimized to the extent practical and, as a goal, shall consist of go-no-go tests.

(b) Maximum use shall be made of flight system capability to reduce the requirements for GSE and other support during ground testing of Space Station System flight systems.

(c) An integrated system ground test shall be made of the initial Space Station.

(d) Physical and functional interfaces between each Space Station element, subsystem, component, and between each payload and the Space Station shall be demonstrated as compatible and functional before being committed to launch.

(e) An integrated logistics system shall be developed and maintained to support maintenance, provisioning, inventory management, and other logistics-related activities in support of flight and ground operations.

(f) The capability to service/deservice consumables within the elements and deservice waste and refuse shall be provided. The capability to install and remove hardware within the elements shall also be provided. These requirements shall also include the capability for late access to the elements at the launch pad where required.

(g) The capability to install elements into the STS (horizontally or vertically), remove elements (horizontally or vertically), troubleshoot returned elements, remove failed components, and install replacement components shall be provided.

(h) A verification program shall be provided to assure that all modifications and upgrades function properly.

(i) Pre-launch operations and associated facilities and equipment shall provide for STS reconfiguration, processing, and launch readiness within 19 days of notification in support of a Space Station rescue mission.

(j) The capability for on-Earth transportation for all Space Station elements to and from any required location shall be provided.

10.1.2 On-Orbit Flight Operations

These operations require that the Space Station shall be operated in a manned mode, where continuous sub-system monitoring by either the flight crew or ground shall not be required for normal Space Station System operations. However, the capability for the crew to status and monitor all subsystem health and status data shall be provided. Activity planning and mission planning capabilities shall be provided for daily housekeeping chores, maintenance and repair schedules, health maintenance and short-term planning for customer mission activities. The on-board information management systems shall provide, as a minimum, system maintenance and trouble-shooting procedures, trend data acquisition and analysis, consumable status, and repair and replace information. On-board operational capability by scientists or payload experts of payload/experiments shall be provided. Scientific/payload data shall be capable of being recovered with a minimum of ground processing. System/subsystem validation shall be performed with a minimum of crew interaction and shall be capable of being initiated automatically or manually. Subsystem reconfiguration in the event of a failure shall be capable of being performed automatically or with crew concurrence. Voice contact with the mission support team and Space Station System health and status data and payload data down-link to the mission ground support system shall be provided.

10.1.2.1 Space Station System Buildup

The following requirements are established for the Space Station System buildup:

(a) The delivery of various Space Station System elements to orbit shall be accomplished by the STS.

(b) Initial assembly, activation, checkout, and operational verification tasks shall be shared by the STS while the Station is in a Shuttle-tended* mode, the Space Station flight crew, and ground control/support.

(c) Permanent crew occupancy shall occur after the manned system is verified and shall initially consist of a crew of up to 8, partially/totally rotated by the STS every 90 days. Customer crew personnel rotation periods shall be variable and negotiable.

(d) The crew shall consist of a mix of Station, mission, and payload specialists. The skill mix shall depend on anticipated activities.

(e) As operational confidence is achieved in the various elements, ground support of their operation shall be phased to an effective mix on on-board control and ground control.

(f) Nominal expendables, spares, payloads, and other equipment shall be packaged into a resupply module and carried to the Station by the STS every 90 days, plus or minus 20 days. Customers may negotiate additional delivery and return of supplies to and from the Station at their expense. Station waste products, failed spares, and mission products shall be returned to the ground by a resupply module carried by the STS. Preflight and postflight resupply module processing shall be accomplished by Space Station ground personnel.

(g) A sufficient number of resupply modules shall be required to support Space Station System operations without interruption in the event of a contingency (e.g., launch abort).

(h) Growth station operations may include 10 or more Station specialists, mission specialists, payload specialists, and other customer personnel such as guest scientists.

(i) Growth station operations shall continue to include Shuttle-tended modes for transfer of equipment to and from the manned Space Station, possibly including cryogenic propellants.

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* Shuttle-tended is defined as that period of time when the Orbiter is docked to the Station or is in close proximity. Nothing more is implied.

(j) Orbital Maneuvering Vehicles (OMVs)* based at the Station, shall provide the necessary orbital maneuvers to bring satellites or platforms into the proximity of the Station for servicing if they do not provide their own propulsion.

(k) An Orbital Transfer Vehicle (OTV) shall be based at the Station to provide the delta velocity necessary to transfer payloads to and from different orbits.

(l) Manned maneuvering units (MMUs) shall provide extravehicular activity (EVA) mobility within the region surrounding the Station.

10.1.2.2 Space Station System Mission Operational Requirements

(a) Mission** activities shall include operation and servicing of internal and externally attached experiments/payloads/laboratories, operating and servicing of platform-mounted experiments/payloads, servicing of free flyers, test and deployment of payloads and upper stages, OMV operations, eventual largescale construction/assembly of payloads, and operation of OTVs.

(b) The Space Station shall have the operational capability for conducting proximity operations with other vehicles.

(c) The Space Station shall operate cooperatively with the co-orbiting platforms and their attached instruments, experiments, and payloads by providing material collection and system/instrument replacement and refurbishment. System monitoring and control and data collection shall be provided on a mission-unique basis and as required during proximity operations.

(d) The Station and Station System shall develop in an evolutionary manner over a period of years. Growth capability during the life of the Space Station System shall be required as a major operational and design consideration.

(e) The Station shall operate in the manned mode unless unforeseen circumstances force evacuation. Unmanned operations at the Station shall, at a minimum, consist of:

(1) Maintenance of orbit, attitude, and systems.

(2) Continuation of certain essential services to attached payload hardware.

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* One or more OMVs may subsequently by geosynchronous Earth orbit (GEO) - based to service GEO satellites.

** Mission is defined as a time sequenced set of events for a specific customer.

(3) Verification of a safe condition in order to man the Space Station.

(f) The Station shall provide non-mission-unique basic services such as coarse instrument pointing; customers shall arrange for mission-unique services.

(g) Onboard flight operations shall nominally be conducted 24 hours a day, 7 days a week.

(h) Communications for command and data handling between the ground and the Space Station System shall be through the Tracking and Data Relay Satellite System (TDRSS) or its replacement system. Voice contact capability and Space Station System/payload health and status data shall be provided by the onboard communication and data systems.

(i) During Orbiter interaction with the Space Station, the Station shall not perform translation or attitude maneuvers during docking/berthing operations.

(j) During periods of STS servicing/resupply, a coordination effort among the platform control function, the Orbiter, and the Station shall be required.

(k) An activity-planning capability support and information display capability shall be required to store and display the daily activity plans, with record/entry by ground and crew.

(l) A management information capability shall be required on board the Space Station and on the ground to provide Space Station System system maintenance and troubleshooting procedures, to track consumable requirements, and to track and record repair and replace information.

(m) Orbital re-boost capability for the Space Station shall be provided. The Space Station shall be capable of maintaining its operational orbit altitude within ± TBD.

10.1.2.3 System Requirements

(a) Since hardware and software systems shall be maintained while on the ground and on orbit, reliability/maintainability shall be a prime consideration in the design of the System.

(b) The Space Station System and its subsystems shall have the capability to be progressively upgraded on orbit as improved technology becomes available. However, any upgrading of the Space Station System or its subsystems shall maintain service commonality with customer applications in existence or under development to the maximum extent possible.

(c) Station System autonomy and onboard machine autonomy shall be emphasized as a goal in order to minimize ground control of the System and crew involvement in system monitoring. Continuous subsystem monitoring and control be either the flight crew or ground shall not be required for normal Space Station System operations in order to maximize high return activities in support of mission operations. However, the capability for the crew and ground to monitor/status all subsystem health and status data shall be provided.

(d) The Space Station System and its subsystems shall be designed such that any single credible failure shall result in a safe condition. Subsequent crew action may be required to restore normal Space Station System operations.

(e) Those Space Station systems that interface directly with the customers (e.g., power, data, cooling) shall have automatic fault detection and remedial/safing capability which will prevent payload operations damaging Space Station systems.

(f) The capability to conduct near-term activity planning shall be provided on board the Space Station, and long-term planning shall be accomplished by the ground.

(1) Near-Term Planning - Planning of daily activities for which information is available on board, including replanning when circumstances have made previous planning unworkable. Some examples are: experiments, general housekeeping tasks, subsystem status checks, failures, payload mission planning, preventive maintenance, and consumable inventory.

(2) Long-Term Planning - Planning that requires the consideration and integration of numerous facts and requirements to which the flight crew may not have access or that can be accomplished more efficiently on the ground.

(g) The System design shall be such that the need for extensive flight crew training is minimized.

(h) Operational procedures, system, and subsystem documentation shall be available in real time through onboard interactive tutorial computer storage. Portable onboard terminals shall be provided to reduce or eliminate onboard paperwork. These terminals shall have a hard copy capability.

(i) Design shall be such that procedures can be standardized for many types of System activity.

(j) Crew time shall be allocated as a resource. For operational and design purposes, it shall be assumed that:

(1) During any 24-hour period, EVAs shall be limited to 8 hours maximum per EVA crewmember.

(2) Nine hours per day per crewmember shall be available for Space Station System and customer operations.

(3) Each crewmember shall be available for Space Station System operations 5 days per week.

(k) The System shall be designed and operated such that the flight crew shall have the ability to change planned activities in order to capture time-critical data from unexpected events or to salvage a payload mission.

(l) Design and operations shall use the Station flight crew for the performance of tasks where man's capabilities produce a cost-effective alternative to automation. The capability shall be provided to progressively automate the Station subsystems as procedures are developed over a period of time to achieve a high degree of automation. The flight crew or ground shall be able to modify, generate, and add or delete application* software in real time with the system on line using the Space Station control consoles.

(m) The Space Station System shall utilize a decentralized mission planning computer system and a distributed Station computer system. These systems shall feature easily understood data interfaces so that the interfaces between data paths and their connections with the data system services may be clearly defined and controlled.

(n) A functionally single operational data base, with backup capability for Station System operations that can be accessed and modified by the flight or ground crews in real time with the system on-line and with appropriate safeguards to prevent accidental or inaccurate modifications, shall be maintained as it evolves through the life cycle of each Station element. This data base shall provide the storage and retrieval capability for functions such as crew procedures, vehicle procedures, library, data archives, mission planning, crew planning, inventory/logistics, medical records, mail, crew entertainment, and provide for limited-life (time/cycle)accountability. This operational data base shall describe the element and its operations in terms of configuration, trend data, traceability, command/data formats, alarms, limits, conversions, display formats, failure history, configuration, etc., and shall become a part of the flight and ground on-line and off-line single operational data base.

(o) Software shall be designed to permit real-time changes with the system on-line, while protecting critical software from inadvertent modification or destruction. Sufficient flexibility shall be built

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* Application software is that software which is resident within the Space Station computers to monitor and control Space Station subsystems and which performs special operational tasks.

into the software systems to permit adjustment, provide audit trail capability, and to prevent the necessity of the crew applying non-standard software procedures.

(p) A Space Station configuration management system shall be provided and shall identify, control, and track the current configuration of each element's hardware, software, electrical, fluid, and mechanical subsystems. Such a system shall reside on the ground and in the Space Station System data base and shall be accessible to both the Space Station crew and ground personnel.

(q) Pre-breathing requirements for EVA shall be minimized.

(r) System and subsystem validation or reconfiguration shall be capable of being initiated automatically or manually.

(s) The capability shall be provided for onboard calibration of equipment requiring high accuracy.

(t) Sufficient margins and modularity shall be established within the data utilities to ensure that functional transparency of these services is maximized.

10.1.3 Ground Control and Support Operational Requirements

The mission ground support system shall provide the capability for the ground support team to support the flight operations during all phases of orbital operations with special emphasis during critical or contingency modes.

(a) Ground control/support functions shall include STS, Space Station, platform, payload control operations, and OMV and OTV operations.

(b) Monitoring of the Shuttle systems and flight dynamics by ground functions will be required during the critical flight phases of launch, landing, rendezvous, and major system failures.

(c) The Space Station ground control/support facility initially shall provide for System monitoring and support. This ground support shall be provided for the platforms, OTV, OMV, and Space Station in the form of flight and system monitoring and assistance during the assembly, activation, checkout, and verification of each new System element; then it shall significantly reduce the real-time monitoring as the System becomes operational. Allocation of functions (from ground to flight) shall follow a planned phaseover as the operation matures and confidence is achieved in the System Element operation.

(d) Routine on-orbit monitoring of onboard systems shall be done using onboard automated equipment with occasional oversight by the crew and with limited periodic review of system data by the ground.

(e) Voice communication support from the ground control facility shall be provided when the Space Station is manned.

(f) Customer training shall be done primarily on the ground. Other training shall be done on the ground and in flight.

(g) Long-range planning shall be done on the ground.

(h) In support of flight dynamics, a routine trajectory service shall be required once the Space Station System is operational. Services to be performed by the Space Station or, as a backup, by the ground shall include orbital maintenance of the Station, OTV, and OMV maneuver planning and tracking, platform tracking, and satellite retrieval planning and tracking. (Orbiter rendevous with the Station or other elements shall continue as an STS function.)

(i) For contingency situations, ground support for onboard problem resolution shall be accomplished using the appropriate facilities that exist during the Space Station program.

(j) Management of Space Station System operations (both manned and unmanned elements) shall be divided between the onboard system and the ground to most effectively utilize the capabilities of each.

(k) Flight crew training shall prepare the crew for the following tasks as required: system monitoring and maintenance, emergencies (including medical), propellant handling, construction/assembly, EVA, OTV and OMV operations, payload and experiment operations, including scheduled and unscheduled maintenance, mission activity planning, and daily routine tasks. Training for ground support personnel shall prepare them for the following tasks: system performance evaluation, system troubleshooting, payload and experiment interface operations, mission activity planning, and failure analysis.

The System design shall be such that the need for extensive flight crew training is minimized (i.e., all crewmembers shall not be trained to do all things). The systems shall facilitate onboard operations by scientists or payload experts with a minimum of specialized system training.

Training for the accomplishment of specialized activities shall be provided for the crew. Adequate cross-training shall be provided to allow backup operation of critical systems. Extensive preflight training shall not be required for infrequent tasks; onboard training aids shall be provided to assist in accomplishing these functions.

(l) The payload ground control/support facilities (POCC) shall provide for autonomous operations since they are separate from the ground support facilities for the Space Station System. A capability shall be provided for the customers to communicate with their payloads from Government- or privately-owned ground control stations.

(m) The Space Station System-provided payload ground support facility (POCC) shall support payload checkout, control, and performance monitoring as provided by customer-supplied equipment, as well as payload mission time-line planning and a limited amount of payload data processing. Use of this facility is a customer option.

10.1.4 Logistics Operational Requirements

(a) An integrated logistics system encompassing maintenance, provisioning, supply support, support equipment, training, packaging/handling and transportation, facilities and technical data/publication shall be established and maintained to support Space Station System flight and ground operations.

(b) Logistics considerations shall be an integral part of all program phases (concept formulation, design, development, and operations).

(c) Life cycle methodologies shall be employed as the basis for system/equipment/component selection, system operation, maintenance and modification.

(d) Logistics for the orbital operation of the Space Station System shall consist of the orderly planning and execution of on-orbit maintenance and repairs, the resupply of consumables, delivery of spare/repair parts, propellant resupply, delivery of return of payloads, the delivery of return of any new or damaged item, and crew rotation.

(e) Logistics operations in space, especially maintenance, shall consider EVA operations to be a limited resource, and Space Station System design and operations shall allow for its judicious use. Logistics operations shall also minimize the need for special skills, soldering, welding, or time-consuming procedures, in order to maximize crew operational availability.

(f) Long-term activity planning shall provide the integration of requirements and schedules for the various logistics tasks. The STS shall provide the means for delivery to the Station or the return to the ground.

(g) In order to minimize the logistics tasks, consideration shall be given, as examples, to the level of system redundancy in Station elements, consumable quantities on board, and maintainability requirements to reduce the frequency of required resupply and repair missions.

(h) The effectiveness of the logistics system in supporting Space Station System operations shall be monitored throughout all program phases and shall be based upon criteria which specify Space Station

System mission success/availability requirements or goals and crew time.

10.2 SAFETY REQUIREMENTS

The requirements governing the ground rules and constraints for safe Space Station operations follow:

(a) Pre-planned operations and design shall provide for redundant habitats (havens/retreats) isolatable from the rest of the Station and capable of sustaining the flight crew for 22 days. Rescue capability for the Space Station crew shall be provided by the STS. Provisions shall be made for crew transfer from each safe haven to the Orbiter.

(b) As a minimum, fail operational/fail safe and restorable levels of redundancy shall be provided in safety-critical systems within the Station System. Critical systems are those systems the loss of which results in injury, loss of life, or damage to the Space Station System.

(c) Emergency equipment, including fire detection and suppression, damage assessment and control capability, life support, and medical, shall be provided within the Station.

(d) Critical systems shall be capable of undergoing maintenance without the interruption of critical services and shall be "fail-safe" while being maintained.

(e) A caution and warning system shall be provided within the Station.

(f) Voice contact between the Station and the EVA crew shall be required. Visual contact between EVA crewmembers or between the Station and the EVA crewmen shall be required.

(g) Ground and on-orbit operations shall provide safe protection for the storage, handling, transportation, processing, launch, use, disposal, and clean-up of flammable, combustible, or hazardous materials.

(h) Flammability, odor, and off-gassing requirements shall be established for materials on the Space Station.

(i) A method for monitoring, detecting, and controlling toxic gas buildup shall be provided on board the Space Station.

(j) Operations and systems design shall provide protection from externally and internally produced radiation/EMI.

(k) Provisions shall be made for ground control of critical Space Station systems (attitude control, environmental control system, etc.) to permit stabilizing the Space Station.

(l) Provisions shall be made for non-hazardous planned disposal of the Space Station flight elements at the end of useful life.

(m) Space Station lines containing toxic/corrosive substances shall not be mounted inside the Space Station environmentally controlled and life supporting pressurized areas.

(n) Space Station protective enclosures shall be provided for all high mass/high speed rotating machinery.

(o) Hazardous pressure vessels shall not be located in the Space Station habitable areas.

(p) Payloads that contain toxic/corrosive substances or pressure vessels shall provide safe containment (e.g., protection from shrapnel or other toxic/corrosive substance release).

(q) Operational warning and evasive capability shall be provided to minimize the probability of collision with orbital debris.

(r) Hazardous energy sources such as propellant or pressure vessels shall be located/designed such that a catastrophic failure in one element or module does not produce a catastrophic failure in adjacent modules or elements.

10.3 OPERATIONAL MEDICAL CARE REQUIREMENTS

Onboard medical care capabilities, including facilities and equipment, shall be appropriate to crew number, operational complexities, and the best assessments of the potential for injury and illness. Environmental hygiene, general habitability concerns, and psychosocial health shall be adequately provided for. Special subsets of these requirements are:

(a) Emergency first aid and life support equipment appropriate to the unique activities of the crew and the working environment.

(b) A medical care facility on board to provide for emergency care, life support, stabilization, on-orbit patient transport (EVA to IVA or intra-IVA), diagnosis, and treatment of ill and injured crewmembers commensurate with established policy, (TBD).

(c) Health maintenance facilities adequate to maintain a healthy, well-conditioned crew and provide recreational exercise.

(d) Environmental hygiene monitoring and analysis equipment suitable for both routine untended operation as well as more critical hands-on analysis and investigations of contingency events.

(e) Generalized health screening pre-launch for the flight crew.

10.4 CUSTOMER OPERATIONAL REQUIREMENTS

To achieve maximum benefits from the Space Station System, design and operations shall provide a high degree of customer interaction with the flight crew and payloads, thus enhancing the effectiveness of the System for the customer. When required, the customer shall provide payload specialists for specific missions. Station data systems for payloads shall be transparent, requiring minimum customer interaction for data reconstruction. Payload Operation Control Centers (POCCs) shall command and monitor payloads independently, subject to safety and compatibility constraints. The operational approach shall be planned so as to reduce requirements placed upon customers by minimizing the number and complexity of interfaces, maximizing customer involvement, and avoiding unnecessary duplication of operations for payloads. Operations and design shall provide a "user friendly" System to facilitate onboard operations by scientists or payload experts without specialized Space Station training. The System shall provide to the customer an affordable, dependable, available, and flexible service. The following requirements are designed to meet these goals:

(a) The Space Station System shall have the capability to service and repair satellites, payloads, and platforms.

(b) Payload operations at the Station and within the System shall include the capability for a high level of customer participation and responsibility.

(c) System operations for experiments and payloads shall place a minimum number of requirements upon customers. Requirements shall be limited to those necessary for safety and customer compatibility. Requirements shall be completely documented in an easily accessible and understandable manner.

(d) The Space Station System and its operation shall provide simple, standard, stable requirements and interfaces for customers of its services.

(e) Operations and design shall provide a "user friendly" System to facilitate onboard operations by scientists or payload experts with a minimum of Space Station specialized training.

(f) The capability shall be provided for independent customer operation and monitoring of payloads including POCC-to-payload command and monitor, consistent with safety and customer compatibility constraints.

(g) Flight and ground data systems supporting payloads shall be transparent to the customer. The Space Station shall provide transparent paths for commands and data between a payload and a payload customer in a manner that does not require the Space Station System to develop mission-unique integrated software.

(h) The Space Station command and data handling system shall be capable of secure communications as required for normal and emergency operating conditions. The command link shall employ command authentication.

(i) Payloads requiring secure command and data handling, either commercial proprietary or national security, shall be responsible for command and data encryption and decryption within the payload and on the ground.

(j) Space Station housekeeping and engineering data transmitted to the ground shall be functionally separate from the payload science data. This will allow for faster data separation and will help insure against unauthorized distribution of proprietary data. In addition, message management techniques shall be employed so that data for individual customers shall be functionally separate.

(k) The Space Station shall provide to the customer, as required, basic Space Station System system/subsystem and ephemeris data.

(l) Payloads to be serviced by the Space Station shall be provided service standards by the Space Station program. The Station shall provide non-mission-unique basic services such as coarse instrument pointing; customers shall arrange for mission-unique services.

(m) The Space Station System shall allow for an optional capability for payloads to provide their own services such as communication, environmental control and life support (ECLS), and/or power subsystems. The Space Station System shall provide non-mission-dependent basic services, and Space Station System software tools shall be made available to customers as a negogiated option.

(n) Payloads shall normally provide their own computational services.

(o) For command and data handling, flight and ground data systems shall be required to receive, process, compress, and retransmit payload data at rates compatible with TDRSS and domestic satellite (DOMSAT). These systems shall be transparent to the customers.

(p) The Space Station shall provide computer terminal equipment that supports keyboard entry, display, and hard copy generation of text and graphics and is functionally identical to commercially available equipment.

(q) The Space Station System shall provide for monitoring and protection of all interfaces that provide data, power, cooling, or similar resources to payloads such that to the greatest extent possible, a payload failure or payload misuse of resources cannot result in adverse impact to other payloads or other Space Station System operations.

(r) The Space Station System shall provide means for simulating the payload interfaces of the Shuttle to allow low cost adaptation of unmanned Space Shuttle payloads to operate on the Space Station System.

(s) Allowable customer service interruption criteria shall be negotiated and established and shall be implemented through redundancy, maintenance, and/or cost policy provisions.

(t) Means shall be provided for determining and charging for customer utilization of services.

10.5 AUTOMATION REQUIREMENTS

The requirements for Space Station Systems autonomous operations are listed in the following paragraphs:

(a) A high degree of Space Station System autonomy* from the ground shall be required. Subsystems shall be as functionally independent as practical in order to facilitate maintenance.

(b) Subsystems shall be automated** to the fullest extent practical. The flight crew or ground shall be able to change automated sequences and limits in real time and on line.

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* Autonomy is an attribute of a system/subsystem that will allow it to operate within its specified performance requirements without external intervention for a specified period of time. This definition does not preclude either man or machine from the system/subsystem design.

** Automation refers to the use of machines to effect control of system/subsystem processes in a predefined or modeled set of circumstances.

(c) System design and operation shall use the flight crew for the performance of tasks where man's capability and utility provide a cost-effective alternative to automation.

(d) Continuous system/subsystem monitoring and control by either the flight crew or ground shall not be required for normal Space Station System operations. Space Station System systems/subsystems shall be designed such that any single credible failure will result in a safe condition. Subsequent crew action may be required to restore normal Space Station System operations.

(e) Station system autonomy and onboard machine autonomy* shall be emphasized to minimize ground control of the Station System and to minimize crew involvement in system/subsystem monitoring. The capability shall be provided to progressively automate systems/subsystems as procedures/designs are developed over a period of time to achieve a high degree of automation. Manually activated devices such as switches, circuit breakers, valves, controls, and doors shall have monitoring feedback mechanisms to enable onboard computers to determine the position or activation of those devices.

(f) The onboard software system shall be user friendly.

(g) A single high order test and control language shall be used to generate and sustain the application software for ground integration, ground test, ground operations, and onboard operations. This language shall be used by Space Station System systems and subsystems and shall be available as an option to customers. This language shall be identified by the acronym LUCC (Language for User Control and Communication). The requirements for LUCC are as follows:

  (1) The language shall be oriented to user control and communications in an operational environment (including test/checkout and bench testing) both on board the Space Station and in all phases of ground usage.

  (2) All phases of language implementation shall be accomplished in a "user positive" manner. Ease and friendliness of use are prime considerations over and above ease of implementation.

  (3) Multiplicity of function shall be minimized and user adaptability shall be emphasized.

  (4) The language shall be easily adaptable, in a very "user friendly" manner, to implementation in an "on-line-immediate/interactive" execution mode.

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* Machine autonomy would reflect the autonomy attribute of a system/subsystem that contains no human elements within its internal boundaries.

(5) The language shall exhibit qualities that simplify implementation of supporting software and additional S/W tools.

(6) The language shall exhibit the qualities of ease of change, modular nature, and explicit functions.

(7) The language constructs shall be natural to the user, with language statements, components, and punctuation closely exhibiting English grammar rules.

(8) The language shall be technically adequate to meet the requirements of all user disciplines.

(9) The language shall strive for readability, writeability, and learnability. It is essential that care be taken to assure a proper implementation resulting in procedure standardization, self-documentation, test repeatability, and flexibility.

(10) The language shall exhibit user (both writer and reviewer) friendliness in all areas.

(11) The language shall maintain H/W independence in the character set, host and target machine independence, and test system independence (via data dictionary concept).

(12) The language shall result in procedures that are configuration manageable and easy to verify/validate.

(13) The language shall be adaptable to the user's environment from manufacturing to on orbit.

(14) The language shall exhibit qualities that help maintain user familiarity in either procedure or immediate execution modes.

(15) The language shall provide the necessary tools for user control of data elements that may be temporarily or permanently restricted or individually user owned.

(h) Maximum use shall be made of flight system capability to reduce the requirements for GSE and other support during ground test of Space Station System flight systems.

(i) The Space Station System design shall allow for implementation of artificial intelligence as technology permits.

(j) All software shall be designed and developed to minimize maintenance costs. All related processes of the software life cycle shall be designed to enhance the maintainability of the software and its related products.

(k) The data utilities shall be self-managing with the allocation and scheduling of data system resources being largely automated and transparent to the user.

(l) The System design shall support the rapid assimilation of new technology (particularly in the technologically volatile areas of data processing and storage) without requiring major redesign or revalidation.

(m) Provisions shall be made for administrative data processing services that permit automation of on-line operational mission management.

(n) Routine management and control of facility management-related systems and subsystems in elements of the Space Station System shall be carried out by onboard automated systems.

(o) Routine resource management (including all consumables) shall be carried out by onboard automated systems.

(p) Onboard automated systems shall be designed to eliminate the need for real-time continuous monitoring by human crew or ground personnel.

(q) Automated system and subsystem management shall include fault detection, fault isolation, and switching of redundant elements at or above the ORU level.

(r) All automated management and control functions and data shall be accessible to crew and/or ground. Manual override control shall be available.

10.6 MAINTAINABILITY/MAINTENANCE REQUIREMENTS FOR HARDWARE AND SOFTWARE

10.6.1 Maintainability/Maintenance

(a) A program level document specifying maintainability requirements shall be developed for on-orbit and ground maintenance.

(b) Since hardware and software systems shall be maintained while on the ground and on orbit, reliability/maintainability shall be a prime consideration in design of the System. Maintenance provisions shall be included in the initial Space Station System design concepts, and all hardware, whether within or outside the pressurized volume, shall be designed so that maintenance or replacement is not precluded. Maintenance design features shall facilitate failure detection, isolation, corrective action, and verification for hardware and software.

(c) Easy removal, repair, and/or replacement of Space Station System equipment shall be required to the lowest practical level. Wherever practical, systems shall be designed such that repair can be accomplished by removal/replacement of subsystems or components. Welds and permanent fixtures shall be avoided.

(d) Systems and subsystems shall be as functionally, mechanically, electrically, and electronically independent as practical to facilitate maintenance.

(e) A data recording/retrieval system(s) for both near-real-time as well as archived data shall be provided.

(f) Provisions shall be included for inspection and assessment of the Space Station System system's/subsystem's condition. The instrumentation system in each Space Station element shall be capable of detecting and isolating failures to the orbital replaceable hardware (ORU) level. Onboard malfunction detection shall be possible without requiring removal of assemblies or components from the affected system/subsystem.

(g) Critical systems shall be capable of undergoing maintenance without the interruption of critical services and shall be "fail safe" while being maintained.

(h) The orbital replaceable hardware (ORUs) shall be designed for ease of on-orbit replacement. The hardware shall be designed or integrated to use common type fasteners, common connectors, and common tools, and to use the same packaging as appropriate. In addition, all connections shall be designed and labeled to preclude improper mating.

(i) A function shall be provided to facilitate unscheduled maintenance. ORUs may be either inside or outside the Station; i.e., intravehicular activity (IVA), EVA or teleoperation/robotic accessed. Provisions shall be made to bring ORUs external to the Station into the pressurized work area to conduct maintenance. EVA may be considered as a means of ORU replacement if analysis indicates a substantial operational advantage, if ground simulation can prove the feasibility of the operation, and if safety analysis indicates no unacceptable crew risks are introduced.

(j) Based on allowable downtime, storage space available, criticality, and reliability considerations, one or more onboard sets of spare ORUs shall be provided. However, customer ORU sparing provisions shall be left to customer option consistent with safety, storage capability, etc., constraints.

(k) EVA operations shall be allocated as a limited resource, and Space Station System design and operations shall allow for judicious use of this resource.

(l) Replacement of subsystem equipment shall not require the removal, replacement, or disconnection of other subsystem equipment. ORU locations shall be designed such that one ORU does not have to be removed to gain access to another.

(m) Adequate clearance shall be provided during the removal or replacement of equipment undergoing maintenance to preclude any interference with other Space Station System operations and to preclude the creation of any safety hazard.

(n) All Space Station System flight and ground system development contractors shall demonstrate that their respective designs meet the program maintainability requirements.

(o) All software shall be designed and developed to minimize maintenance costs. All related processes of the software life cycle shall be designed to enhance the maintainability of the software and its related products.

(p) The Space Station System shall include a closed-loop system for the reporting of all problems (failures and unsatisfactory condition reports) and shall establish a corrective action for all problems concerning flight, test, simulator, and training hardware where that hardware is representative of flight hardware, GSE, applicable GFE, and spare hardware. Analysis of problems reported shall be performed to determine the cause and to implement adequate measures to prevent recurrence.

(q) The Space Station design shall include controlled storage facilities for storing usable spares and test equipment and will provide for segregation of discrepant equipment pending disposition.

10.6.2 Commonality

(a) ORUs shall require standardization where feasible for direct interchangeability.

(b) Commonality and interchangeability of both hardware and software shall be required at least to the ORU level or its equivalent. This applies to both flight and ground systems. Predefined interface standards identical to or compatible with generally established space standards shall be used between the Space Station elements and, as appropriate, between Space Station subsystems.

(c) Hardware and technology commonality shall be applied to the design of on-orbit replaceable hardware to simplify the logistics and maintenance activity and to minimize program costs. This commonality applies to ground and flight hardware and software alike. Commonality will also reduce spare storage.

10.7 HABITABILITY REQUIREMENTS

Habitability is a discipline (like Safety or Reliability) that contributes to the well-being, morale, and health of the crew. It is a discipline concerned with comfort, ease of use, avoidance of nuisances, and other human factors. It is not concerned with basic survival. Operational habitability requirement that are related to automation, safety, maintainability, commonality, customer interfaces, or logistics have already been addressed specifically in preceding sections. In this section are defined the operational habitability requirements that deal with the morale, psychological and physiological well-being, health, comfort, and other human factors of the crew. These requirements are designed to maintain morale and increase productivity among and for crewmembers. These requirements follow:

(a) Comfortable accommodations shall be provided for the 5 to 95 percentile male and female crewmembers, except for EVA operations.

(b) The ECLS system (ECLSS) shall provide adequate, shirtsleeve, breathable, and odor-free atmosphere for the crew.

(c) The ECLSS shall maintain a comfortable temperature in all habitable areas of the Space Station and shall provide for temperature control by the crewmembers.

(d) The Station shall provide adequate lighting types and levels/variable controls and sunlight control in all habitable areas. Adequate light shall be available for all tasks, as well as for living within the Station. In addition, adequate portable lighting devices shall be placed strategicly throughout the Station.

(e) Particular care shall be maintained to prevent shadowing, high contrast, glare, and light shining directly into the eyes of crewmembers.

(f) The Station shall provide sufficient sound control to reduce all Station-produced noises to the minimum level reasonably achievable and in accordance with specifications (TBD). Crewmembers must be able to converse without shouting, and must be able to hear the various caution/warning systems and communication systems without specialized hearing aids or locations. Special considerations shall be given to the noise levels in the sleeping quarters, but the sleeping quarters shall not be so quiet that a caution and warning alarm cannot be heard.

(g) The geometric arrangement of compartments shall provide the necessary and adequate access, egress, volumes, and envelopes to all functions within the Station. Traffic patterns shall be considered of prime importance, and station layout, facilities, and activities shall be designed to the zero-gravity neutral body posture.

(h) A common visual local-vertical orientation shall be provided in all habitable areas of the Space Station.

(i) Interior areas shall be designed for a maximum of TBD hours of housecleaning per day/week. Housecleaning materials and equipment shall be accessible.

(j) A separate wardroom for crew dining and for crew lounging/meetings shall be provided.

(k) Interior coloring, appointments, decoration, and furniture arrangement shall provide a sense of visual space, stimulation, orientation, stowage/equipment location aids, and a soothing and restful surrounding for the crewmembers, depending on the function of the area. In addition, provisions shall be made so that the crew can find critical valves, switches, etc., in the dark by touching recognizable textures and shapes. These devices shall be placed in standard positions.

(l) Provisions for rearranging the decor and color shall be provided.

(m) Private rest areas shall be provided for all crewmembers. These areas shall be separated from other noise-producing areas, eating areas, and toilet/hygienic areas. Private rest and sleeping quarters shall also provide for caution/warning alarms, storage of personal items, desk facilities, a bulletin board, a method of securing clothes, and books. These quarters shall be large enough for donning/removing of clothes.

(n) Adequate observation windows for work-related tasks and recreation shall be provided. These windows shall provide for easy, comfortable, and convenient viewing for more than one person at a time. Window work stations shall have provisions for attaching needed equipment in the window area.

(o) Stowage items shall be located as close to their use location as practical. Unstowing and accurate restowing shall be made as easy as possible for crewmembers. Common latching devices shall be used throughout the Station. Visual aids shall be designed to help the crewmembers locate all stowage items.

(p) The Station System shall provide crew and equipment with sufficient restraints and locomotion aids to enable the crewmembers to function efficiently and effectively. These restraints and locomotion aids shall easily engage and disengage.

(q) Hatches and doors internal to a single module shall be configured to allow pass-through without body reorientation.

(r) The interior of the Station shall be as devoid as possible of all sharp-edged surfaces and protrusions. Switches will be placed/guarded to preclude accidental change-of-state by being bumped by a crewmember.

(s) Panels and displays shall be designed to good human factors criteria and shall be easy to read and use, especially in an emergency situation.

(t) Clocks indicating day and time shall be placed strategically throughout the Station.

(u) Varied, palatable, nutritionally balanced, hot and cold food and drink shall be provided for crewmembers. Snack items shall also be provided.

(v) Galley provisions shall be separated from private sleeping quarters and toilet/hygienic areas and shall provide for hot and cold meal preparations, stowage of utensils, storage and preservation of food, cleanup and trash management, and stowage of condiments and accouterments necessary for food preparation and eating.

(w) The Station shall provide crews with adequate clothing for working, hazardous operations, off-duty time, and sleeping. The cleaning/washing facilities to maintain that clothing shall be provided. The clothing should be varied in color and style, be easy to don and remove, have adequate pockets, be flame resistant and cleanable, and provide the proper protection during hazardous operations.

(x) Private toilet facilities for fecal, vomitus, and urine collection and safe disposal that are adequate, numerous, simple-to-operate, maintain, and clean shall be provided. These toilet facilities shall be large enough to don, remove, and temporarily secure clothing and shall include a hand washer. These toilet facilities shall not generate more than TBD noise.

(y) Personal hygiene, bathing, and shaving facilities shall be provided by the Station. These facilities shall be private and separated from eating areas.

(z) The habitat shall be arranged and designed to facilitate the stabilization and storage of trash. The equipment necessary for trash storage and stabilization shall be conveniently located for collection and use by all crewmembers.

(aa) Adequate free time for recreational purposes and exercising shall be provided for each crewmember. Adequate recreational devices such as books, computer terminals, music, movies, and an exercise apparatus shall be provided to each crewmember. Adequate time shall also be provided to each crewmember for leisure and sleep.

(ab) Adequate person-to-person communications between the Station and the ground and within the Station shall be provided. Provisions for private 2-way communications with family members on the ground shall be provided (TV and voice). No censorship of communications between crewmembers and their families shall be imposed unless for National Security reasons.

(ac) Particular attention shall be given to optimizing the crew number and crew mix.

(ad) Efforts shall be made to match crewmembers according to compatibility and provide small group dynamics training to each crewmember prior to flight.

(ae) Proper command structure and authority schemes shall be developed for the crew before flight. The crewmembers shall participate in the development of any command authority scheme.

(af) Efforts shall be made to provide training for families of crewmembers before flight and to supply some support network for them during and after the flight.

10.8 OPERATIONAL SECURITY REQUIREMENTS

(a) The Space Station command and data handling system shall be capable of secure communications as required for normal and emergency operating conditions. The command link shall employ command authentication.

(b) Payloads requiring secure command and data handling, either commercial proprietary or national security, shall be responsible for command and data encryption and decryption within the payload and on the ground.

(c) Secure voice/video communications shall be provided between the flight crew and the ground.

(d) Secure provisions for hands-on and visual access to payloads shall be provided, as negotiated with the customer.

10.9 OPERATIONAL QUALITY ASSURANCE

(a) A program level document specifying quality assurance requirements, disciplines, and controls shall be developed for equipment and software for implementation during ground and on-orbit operations.

(b) Quality assurance goals and requirements shall be established. An effective system shall be implemented that validates the acceptability and conformance of hardware/software and its operation.

(c) Prevention of defects and correction of causes to prevent recurrence shall be a prime consideration of the quality effort.

APPENDIX A

SPACE STATION OPERATIONS STUDY PLAN

(Published Separately)

APPENDIX B

SECOND LEVEL WHITE PAPERS

(Published Separately)

APPENDIX C

FIRST LEVEL WHITE PAPERS

(Published Separately)

APPENDIX D

OPERATIONAL REQUIREMENTS TRACEABILITY MATRIX

(Published Separately)

APPENDIX E

SPACE STATION PROGRAM DESCRIPTION DOCUMENT

LIST OF ACRONYMS

APPENDIX E

SPACE STATION PROGRAM DESCRIPTION DOCUMENT

List of Acronyms

AAC	Advanced Adaptive Control
ACD	Attitude Control Development
ACD	Advanced Control Devices
ACG	Atmospheric Composition Payload Group
ACS	Attitude Control System
ADG	Atmospheric Dynamic Payload Group
AEPI	Space Plasma Physics Low Light TV
ALT	Radar Altimeter
ASO	Advanced Solar Observatory
ATMOS	Atmospheric Trace Molecules Spectrometer
AVHRR	Advanced Very High Resolution Radiometer
AXAF	Advanced X-Ray Astronomical Facility
AXET	Space Plasma Physics X-Ray Telescope
BHFT	Basic Human Factor Technology
BIT	Built-In-Test
BITE	Built-In-Test Equipment
BP	Biological Processing
BPM	Biological Production Module
C^3	Command, Control, and Communication
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
CAP	Controlled Acceleration Propulsion
CCTV	Closed Circuit Television
CDG	Concept Development Group
CDM	Corona Diagnostic Mission

CELSS	Closed Environmental Life Support System
CFS	Cryogenic Fluid Storage
CFT	Crew Factors Technology Group
CG	Center of Gravity
CG	Crystal Growth
CGSP	Crystal Growth and Solidification Processes
CLS	Contingency Landing Site
CM	Centimeter
CMG	Cryosphere Monitoring Payload Group
CML	Commercial MPS Lab
C/O	Checkout
COMF	Combustion Facility
CONT	Contamination Technology
COORD	Coordination
CP	Containerless Processing
CRM	Chemical Release Module
CRY	Cryogenics
CSOC	Consolidated Space Operations Center
CTMS	Commercial Teleoperator Maneuvering System
CWFS	Wind Field Scatterometer
DBS	Direct Broadcast Satellites
DC	Direct Current
DCLS	Data Collection and Location System
DOD	Department of Defense
DOMSAT	Domestic Satellite
DROP	Liquid Droplet Radiator
DSCG	Directional Solidification Crystal Growth
ECG	Electroepitaxial Crystal Growth

ECLSS	Environmental Control and Life Support System
EEG	Electroencephalogram
EKG	Electrocardiogram
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMG	Electromyograph
EMU	Extravehicular Mobility Unit
EOG	Electro-Oculogram
EOS	Electrophoresis Operations in Space
EOSD	Earth Observations Sensor Development Laboratory
ESA	European Space Agency
ESR	Earth Science Research
EVA	Extravehicular Activity
FBT	Feedback Technology
FCP	Fluid and Chemical Processing
FLD	Fluid Dynamics
FMT	Fluid Management Technology Group
FST	Fire Safety Technology
FTS	Fourier Transform Spectrometer
FUSE	Far Ultraviolet Spectroscopy Explorer
GEO	Geosynchronous Earth Orbit
GEOS	Geodynamic Experimental Ocean Satellite
GeV	Giga-electron Volts
GLSC	Government Launch Services (Cryogenic)
GLSS	Government Launch Services (Storable)
GMS	Geostationary Meteorological Satellite
GPS	Global Positioning System

GRE	Gravitational Redshift Experiment
GRM	Geopotential Research Mission
GRO	Gamma Ray Observatory
GSE	Ground Support Equipment
GSFC	Robert H. Goddard Space Flight Center
GSLA	Government Large Structures Assembly
GSSF	Government Satellite Services Facility
H_2	Hydrogen
HABT	Habitability Technology
HEIE	High Energy Isotope Experiment
HEO	High Earth Orbit
HLAG	High Inclination Low Energy Astronomy Payload Group
HM	Habitat Module
HMF	Health Management Facility
HRS	High Resolution X-Ray and Gamma-Ray Spectrometer
HTM	High Throughput Mission
HVPI	Hi Voltage Plasma Interaction
H/W	Hardware
H_z	Hertz
IEF	Isoelectric Focussing
1-g	One-G
IGSE	Instrumentational Ground Support Equipment
ILSA	Industry Large Structures Assembly
ILSC	Industry Launch Services (Cryogenic)
ILSS	Industry Launch Services (Storable)
IOC	Initial Operational Capability
IRL	IR Lidar

IRU	IVA Replacement Unit
IS	Imaging Spectrometer
ISO	Space Plasma Physics UV and Visible
ISSF	Industry Satellite Services Facility
IUS	Interim Upper Stage
IVA	Intravehicular Activity
JEA	Joint Endeavor Agreement
JSC	Lyndon B. Johnson Space Center (NASA)
KeV	Kilo-electron Volt
KM	Kilometer
KSC	John F. Kennedy Space Center (NASA)
KW	Killowatts
LACO	Laser Communications
LAMAR	Large Area Modular Array
LAP	Leased Attached Pallet
LARS	Lower Atmosphere Research Satellite
LASMMR	Large Aperture Scanning Mutli-frequency Microwave Radiometer
LCC	Launch Control Center
LD	Luminescence Detector
LDEF	Long Duration Exposure Facility
LDR	Large Deployable Reflector
LEEC	Laser to Electric Energy Conversion
LEO	Low Earth Orbit
LeRc	Lewis Research Center (NASA)
LGMT	Low-G Materials Technology Group
LHAG	Low Inclination High Energy Astronomy Payload Group
LIDAR	Light Radar (Meteorological Instrument)

LLAG	Low Inclination Low Energy Astronomy Payload Group
LPT	Laser Propulsion Test
LSB	Leased Spacecraft Bus
LSC	Large Solar Concentration
LRS	Laser Reflectance Spectrometer
LST	Large Structure Technology Group
LSTE	Large Structures Technology Experiment
LTD	Large Space Antenna Technology Development
LUCC	Language for User Control and Communication
M^3	Cubic Meters
MAC	Materials and Coatings
MBA	Multiple Berthing Adapter
MCC	Mission Control Center - JSC
MDAC	McDonnell Douglas Corporation
MDD	Mission Description Document
METSAT	Meteorological Satellite
MeV	Mega-electron Volts
MGP	Micro-G Physics and Chemistry Experiments Group
MHAC	Multi-frequency High-Gain Antenna Configuration
MHD	Magneto Heterdynamics
MILSTAR	Military Satellite
MLA	Multi-spectral Thermal Infrared Imager
MMS	Manned Maneuvering System
MMU	Manned Maneuvering Units
MP	Space Plasma Physics Multiprobes
MPC	Multiple Payload Carrier
MPE	Materials Performance Technology Group

MPF	MPS Products Facility
MPS	Materials Processing in Space
MPTL	Material Processing Technology Laboratory
MRWG	Mission Requirements Working Group
MSAR	Mzulti-frequency, multi-polarization, multi-lookangle, Synthetic Aperture Radar
MSFC	Marshall Space Flight Center (NASA)
MTCT	Manipulator/Teleoperator Control Technology
MTIRI	Multi-spectral Thermal Infrared Imager
NASA	National Aeronautics and Space Administration
NMI	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
O_2	Oxygen
OAST	Office of Astronautic and Space Technology
OCI	Ocean Color Imager
OJT	On-The-Job-Training
OMG	Ocean Monitoring Payload Group
OMP	Ocean Microwave Package
OMV	Orbital Maneuvering Vehicle (also referred to as TMS)
OPEN	Origin of Plasma in Earth Neighborhood
OPF	Orbiter Processing Facility
ORU	Orbital Replacement Unit
OSSA	Office of Space Science and Applications
OST	OTV Servicing Technology
OTV	Orbital Transfer Vehicle
OVLBI	Orbiting Very Long Baseline Interferometry
PACE	Physics and Chemistry Experiments
PGSE	Payload Ground Support Equipment

PI	Principal Investigator
PL, P/L	Payload
PMS	Polar Meteorological Satellite
POCC	Payload Operations Control Center
POF	Pinhole Occulter Facility
POT	Proximity Operation Trainer
POV	Proximity Operation Vehicle
PPL	Plant Physiology Laboratory
PPPL	Planetary Physical Processes Laboratory
PSS	Polar Subsurface Sounder
PST	Planetary Spectroscopy Telescope
R&D	Research and Development
RCS	Reaction Control System
RF	Radio Frequency
RFP	Request for Proposal
RM	Resupply Module
RMS	Orbiter Remote Manipulator System
ROTV	Returnable Orbital Transfer Vehicle
RPDP	Recoverable Space Plasma Physics Sub-Satellite
RPL	Rodent and Primate Laboratory
RRG	Earth Resources Payload Group
RSS	Rotating Service Structure
SAB	Space Applications Board
SADOT	Structures Assembly, Deployment, and Operations Technology
SAR	Synthetic Aperature Radar
SC	Solar Concentrator Group
SCAT	Scatterometer

SCB	Space Science Board
SCDM	Solar Corona Diagnostic Mission
SCL	Space Component Lifetime
SCM	Spacecraft Materials
SCRN	Energy Spectra of Cosmic Ray Nuclei
SDL	Sensor Development Lab Group
SDLT	Static/Dynamic Load Technology
SEPAC	Space Plasma Physics Particle Injection
SET	Servicing Technology Group
SI	Stereo Imaging
SIDM	Solar Internal Dynamics Mission
SIRTF	Shuttle Infrared Telescope Facility
SL	STARLAB
SLA	Scanning Laser Altimeter
SLF	Shuttle Landing Facility
SM	Space Plasma Physics Solar Monitor
SMM	Solar Maximum Mission
SOT	Solar Optical Telescope
SOT	Structural Operations Technology Group
SPC	Space Polymer Chemistry
SPL	Solar Pumped Laser
SPLF	Station/Platform Lidar Facility
SPP	Solar Pumped Plasma
SPPG	Space Plasma Physics Payload Group
SPS	Solar Pointing Structure Group
SPT	Solar Panel Technology
SR&QA	Safety, Reliability, and Quality Assurance

SS	Space Station (also referred to as "The Station")
SS RMS	Remote Manipulator System based on the Space Station
SSS	Space Station System (also referred to as "The System" or as "The Space Station Element")
SSAR	Stereo Synthetic Aperture Radar
SSE	Solar System Exploration
SSST	Space Station System Trainer
SST	Satellite Servicing Technology
ST	Space Telescope
STC	Satellite Test Center
STO	Solar Terrestrial Observatory
STS	Space Transportation System
S/W	Software
TBD	To Be Determined
TD	Technology Development
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TeV	Tera-electron Volts
TMS	Teleoperator Maneuvering System (also referred to as OMV)
TOPEX	Topography Experiment
TRIC	Transition Radiation and Ionization Calorimeter
TSC	Thermal Shape Control
TV	Television
UARS	Upper Atmosphere Research Satellite
UM	Utility Module
USRA	United States Research Association
UV	Ultraviolet
VAB	Vehicle Assembly Building

VAFB	Vandenberg Air Force Base
VCG	Vapor Crystal Growth
VLBI	Very Long Baseline Interferometer
WETF	Weightless Environment Training Facility
WISP	Space Plasma Physics Wave Injection
WS	Windsat
XTE	X-Ray Timing Explorer
ZAR	Zero-G Antenna Range

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National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 7

PROGRAM PLAN

Prepared By The:
SPACE STATION TASK FORCE

MARCH 1984

FINAL EDITION

NASA

National Aeronautics and
Space Administration

SPACE STATION
PROGRAM DESCRIPTION DOCUMENT

BOOK 7
PROGRAM PLAN

Approved By:

JOHN D. HODGE
Director
Space Station Task Force

PREFACE

THIS DOCUMENT IS ONE OF A SET OF SIX VOLUMES. THE SET IS CALLED THE SPACE STATION PROGRAM DESCRIPTION DOCUMENT. THE SET CONSISTS OF:

BOOK 1	INTRODUCTION AND SUMMARY
BOOK 2	MISSION DESCRIPTION
BOOK 3	SYSTEM REQUIREMENTS AND CHARACTERISTICS
BOOK 4	ADVANCED DEVELOPMENT
BOOK 5	DELETED AS A SEPARATE BOOK
BOOK 6	SYSTEM OPERATIONS
BOOK 7	PROGRAM PLAN

SPACE STATION PROGRAM PLAN

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1.0 INTRODUCTION

To assure U.S. leadership in space in the 1990's, NASA has begun a Space Station Program pursuant to President Reagan's directive in his 1984 State of the Union Address. In this message, the President directed the Agency to develop a permanently manned Space Station within a decade. The Station will be multi-functional and evolutionary in nature. It will significantly enhance the national capability to utilize the unique vantage point and environment of space.

The Space Station Program will consist of a collection of manned and unmanned elements to be developed as an integrated program. The following definitions have been established for the Space Station program. (A more detailed Space Station lexicon has been prepared in draft form. When approved, it will be a controlled document and will contain all appropriate Space Station definitions).

<u>Space Station Program</u>: The collection of manned, unmanned, and transportation projects to be developed as an integrated program leading to a permanent presence in space.

<u>Space Station</u>: The collection of physically attached elements that provide an operational, habitable facility in space.

<u>Space Station Element</u>: The first level at which the Space Station can be subdivided by module or function; the level at which a Space Station can be structurally subdivided for compatibility with the Space Transportation System.

<u>Space Station Program Work Packages</u>: The collection of Space Station Program tasks that are aggregated for center assignment and/or contracting.

<u>Module</u>: An attached Space Station element which provides a unique or common function for Space Station operations.

Free Flyer: Any free-flying, unmanned satellite that is serviced by or otherwise dependent upon the Space Station for its long-term operation.

Platform: An unmanned, free-flying, multi-use spacecraft capable of supplying limited utilities to changeable payloads and an integral part of the Space Station program.

Test Bed: A facility that provides an environment to test advanced development hardware in an integrated system.

Initial Operational Capability (IOC): The point in the development of a Space Station at which the essential capabilities are first operational.

Orbital Maneuvering Vehicle (OMV): A propulsion spacecraft that will use the Space Station as an operating base. The OMV will deploy and retrieve satellites operating in proximity to or co-orbiting with the Space Station and will provide a capability for spacecraft servicing.

Orbital Transfer Vehicle (OTV): A propulsive vehicle that will boost payloads from low Earth orbit into higher orbits or interplanetary trajectories. The OTV is remotely controlled from the ground and/or Space Station. The OTV may also be used to retrieve satellites from higher orbits and return them to the Space Station.

1.1 PURPOSE OF PLAN

The purpose of this Program Plan is to describe the overall technical, management, and procurement approaches for the Space Station program. The plan is structured so that it briefly describes the Program and summarizes the activities entailed in implementing the Space Station Program. It also describes the technical and management plans, procurement strategy, schedules, and resources required to implement the Program. The primary emphasis at this time is on the definition and preliminary design phase and the planning and definition of issues associated with progressing into the Program development phase. As the Program matures, this document will be revised to provide greater detail on program development and follow-on phases of the Program.

1.2 PROGRAM PHASES

The planning schedule for the Space Station Program is shown in Figure 1-1. All planning activities are geared toward an initial operational capability

(IOC) in the early 1990's. The schedule includes planning activities to support the evolutionary process developing from the IOC and leading to a growth capability in the year 2000.

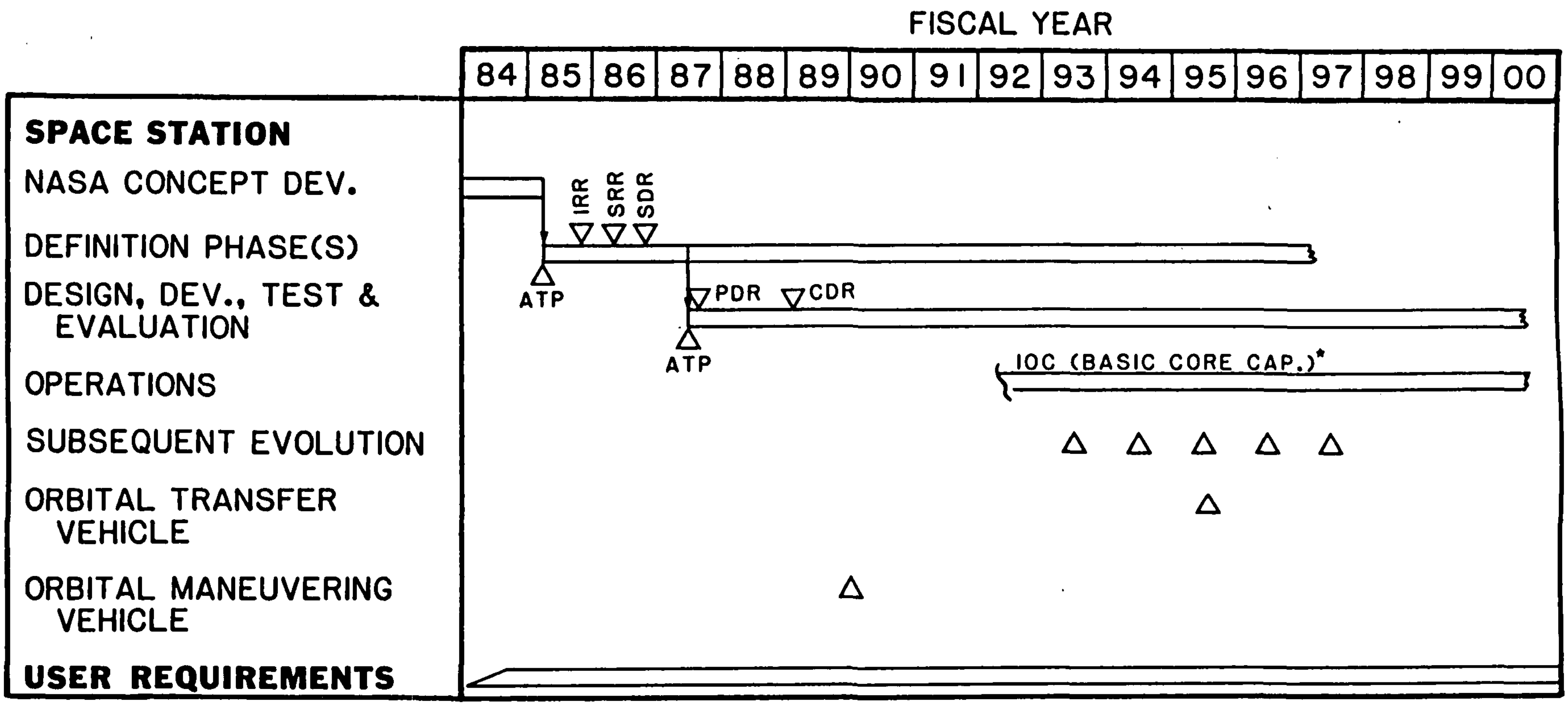
1.2.1 Definition Phase

Because the Space Station Program is a long-term effort, it is essential that corporate memory for Space Station be retained within a single entity. Thus, NASA will perform the systems integration and engineering (SE&I) tasks in-house. The initial definition phase, including preliminary design, will be conducted in FY 85 through FY 87 and incorporate the recommendation of the Hearth Committee Report. While the initial definition phase provides the preliminary design for the IOC, it will also provide for design growth capability for the year 2000 and beyond. During the definition phase, NASA will define customer mission, operations and systems requirements, perform supporting systems and trade studies, develop a preliminary system design, develop and test prototype hardware/software utilizing test beds, define system interfaces, develop costs and schedules, and prepare detailed plans for the development phase. These functions will require the continued participation of the customer during all Program phases.

1.2.2 Development Phase

The purpose of the development phase is to design, manufacture, integrate, verify, test, deliver, assemble on orbit, and test the Space Station Elements with initial operational capability (IOC) in the early 1990's. The initiation of the development phase is planned to start in FY 87. Development is planned to continue beyond IOC to support growth capability in the year 2000.

FIGURE 1-1
SPACE STATION OVERALL SCHEDULE



ATP - AUTHORITY TO PROCEED
CDR - CRITICAL DESIGN REVIEW
IRR - INTERFACE REQUIREMENTS REVIEW
PDR - PRELIMINARY DESIGN REVIEW
SDR - SYSTEM DESIGN REVIEW
SRR - SYSTEM REQUIREMENTS REVIEW

△ - INCREASED CAPABILITY
* - ON-BOARD EXPERIMENTS, SERVICE, AND PLATFORMS

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2.0 PROGRAM CONTENT

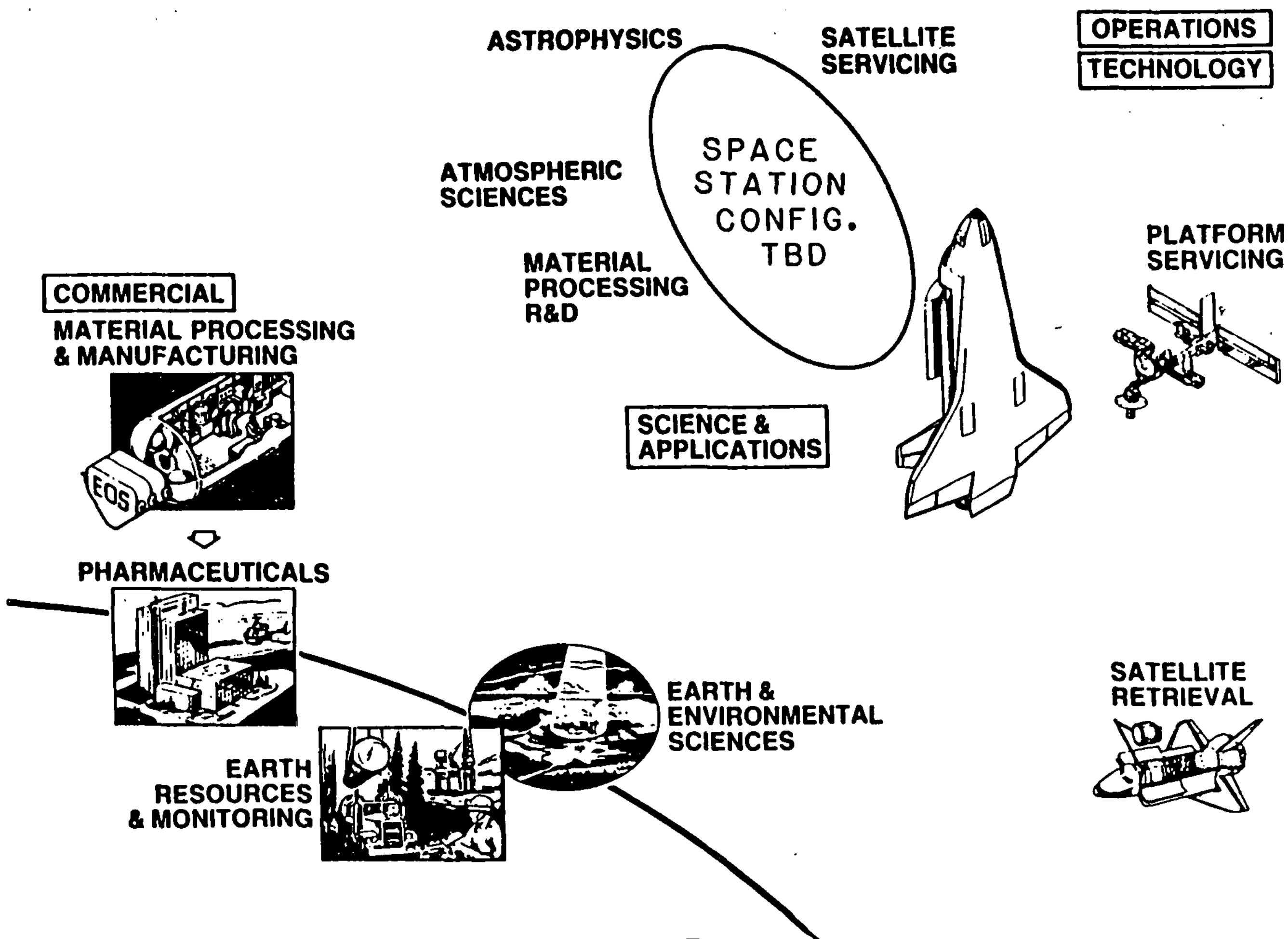
The Space Station will be the central base for operations in low inclination, low altitude Earth orbit. Depending on the identification of requirements, the Space Station may be replicated, in whole or in part, in more than one orbital inclination, and even in high altitude, geosynchronous orbit. It will evolve to be capable of tending independently orbiting unmanned platforms and free flyers, servicing and launching upper stages to geosynchronous Earth orbit or to deep space, and providing facilities for research, development, and commercial endeavors in space. Placement, assembly, resupply, and servicing of the Space Station will be by the Space Transportation System.

2.1 INITIAL OPERATIONAL CAPABILITY

Estimated at $8 billion in FY 84 dollars, the initial Space Station includes both the definition and development phases for the IOC. Funding is included for the development of capability for logistics, crew habitation, laboratory research, resources, multiple berthing, two platforms (polar and low inclination), servicing, and operations. In addition, the initial Space Station Development Program includes the purchase of Orbital Maneuvering Vehicle(s) and remote manipulator systems. The Development Program also covers a variety of Program support functions at the various NASA centers. These functions include astronaut training, customer mission planning, development of customer and facility operations control center support, logistics management, development of EVA capability, and Program integration. The initial Space Station Program does not include Shuttle modifications, Shuttle flight costs, costs of Space Station or STS operations, spares (initial and replenishment), payload costs, cost of facilities (new or modified), and research and Program management (RPM).

An initial Space Station Program concept, as shown in Figure 2-1, would satisfy initial customer requirements by providing manned habitation, electrical power, data handling systems, thermal control, and laboratories for science and applications. The Orbital Maneuvering Vehicle and multiple berthing would support satellite servicing, logistics, and day to day operations. This Program will also include special payload platforms and the capability to service them.

FIGURE 2-1
SPACE STATION
INITIAL OPERATIONAL CAPABILITY



2.2 GROWTH CAPABILITY

The initial capability is planned to evolve with emerging technology and advanced developments and customer requirements into the Space Station of the 2000's and beyond. Additional capabilities might include additional resources, crew members, electrical power, and thermal control, capabilities to place and retrieve payloads into higher orbit, service and repair satellites, resupply vehicles, provide additional laboratory space, and many other capabilities to satisfy projected scientific, commercial, and security needs.

3.0 PROGRAM GOAL AND OBJECTIVES

The goals of the Space Station Program as directed by President Reagan in his State of the Union Message on January 25, 1984, are for NASA to:

- Develop a permanently-manned Space Station and to do it within a decade;
- Invite other countries to participate; and
- Promote private sector investment in space.

In support of these goals, the following long-term, Space Station Program objectives have been established by NASA:

- Establish the means for permanent presence of people in space;
- Enable routine, continuous utilization of space for science, applications, technology development, commercial exploitation, national security, and operations;
- Develop and exploit the synergism of the man/machine combination in space;
- Provide essential system elements and operational practices for an integrated national space capability; and
- Reduce the cost and complexity of working and living in space.

3.1 PROGRAM GUIDELINES

The planning guidelines are divided into management and engineering-related categories as shown in Table 3-1. The management-related guidelines include a comprehensive definition effort of approximately three years with an investment of 5 to 10 percent of the estimated cost of initial capability. The engineering guidelines include provisions for continuous habitation, evolutionary growth through maintainable and restorable systems, manned and unmanned elements, autonomous operations, and the ability to upgrade systems as new technology becomes available. The entire system will be user-oriented for flexibility and simplicity of user interfaces.

TABLE 3-1
SPACE STATION PLANNING GUIDELINES

MANAGEMENT RELATED

- Three year extensive definition (5-10% of program cost)
- NASA-wide participation
- Development funding in FY 1987
- IOC: early 1990's
- Cost of initial capability: $8.0B
- Extensive user involvement
  - Science and applications
  - Technology
  - Commercial
- International participation

ENGINEERING RELATED

- Continuously habitable
- Shuttle dependent
- Manned and unmanned elements
- Evolutionary
- Maintainable/restorable
- Operationally autonomous
- Customer friendly
- Technology transparent

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The Space Station will be in a circular low Earth orbit (LEO) for Shuttle access. It will be Shuttle compatible for delivery, assembly, resupply, and disassembly.

It shall have a design goal for indefinite life through on-orbit maintenance, repair, or replacement.

4.0 MANAGEMENT APPROACH

This section describes the Program management structure, participants and their responsibilities, and the Program control system. Procedures for direction, review and reporting, documentation and information management are also included.

4.1 PROGRAM PARTICIPATION

The Space Station Program will be a national commitment; one that will involve NASA, other U.S. government agencies and departments, private commercial customers, and an activity involving international space agencies. A concerted effort will be initiated in the definition phase to identify domestic and international participants and to define their degree of involvement. The following paragraphs summarize potential participation in the Space Station Program.

4.1.1 National Aeronautics and Space Administration (NASA)

NASA is the responsible Government agency for managing and directing all aspects of the Space Station Program including the definition of requirements, Program definition, design and development, and operations. As required, NASA will work through the Department of State to coordinate international government participation and will work directly with the various U.S. Government agencies and departments in defining their respective involvements and/or requirements. As appropriate, memoranda of understanding and interagency agreements will be developed with participants to define roles, responsibilities, financial arrangements, and management relationships.

4.1.2 Department of Defense (DOD)

Because the Space Station will be a national facility, it will be available for use by all Government agencies, including the Department of Defense (DOD). At present the Department has identified no current requirements for military man in space. The Space Station, therefore, is being designed on the basis of civil requirements. It is conceivable however, that in the future there could be technology experiments conducted on the Station by the DOD.

4.1.3 Other Government Agencies

Other Government agencies may be involved in the Space Station Program. Discussions will be held with interested agencies to define their potential involvement in the Space Station Program.

4.1.4 International Participation

A basic goal of our National Space Policy is the encouragement of international cooperative activities in the national interest. A major Space Station Program planning guideline has been the potential for international participation in the provision of station capability. When President Reagan directed NASA to develop a permanently-manned Space Station, he also invited our international friends to join us.

Substantial international interest has surfaced during NASA's Space Station planning activities. Parallel mission requirements studies have been conducted by Canada, The European Space Agency (ESA), France, Germany, Italy, and Japan and the results have been shared with NASA. These foreign entities are studying potential participation in the definition and development phases of the Program.
Consistent with NASA guidelines on international cooperation, funding for such activities will be provided by foreign governments or specific participants as opposed to U.S. funding. Management and funding mechanisms are currently under study.

4.1.5 Commercial Customers

An inherent part of the Space Station Program is the space commercialization initiative. It is designed to bring an influx of private investment into the space Program. NASA will take steps to expand the commercial uses of space by inviting private companies to partake in manufacturing, processing, and other ventures that take advantage of the zero gravity of the space environment.

4.1.6 Academia

Educational institutions will be actively involved to define requirements affecting the Space Station design.

4.2 PROGRAM MANAGEMENT

The Space Station Program Office will evolve from the Space Station Task Force to one that will ultimately manage the system definition, development, and operation phases of the Program.

4.2.1 NASA Headquarters

The overall NASA Headquarters organization and the relationship of the Headquarters offices with each other and NASA Field Centers is shown in Figure 4-1. Figure 4-2 shows a three-tiered management hierarchy established with Field Centers (Levels A, B, and C). Their responsibilities are described below.

In order to establish agreed upon roles and responsibilities and distribution of funds between the Headquarters offices and Field Centers, formal agreements will be made. Those will be in the form of Program and Project Initiation Agreements established at the various management levels.

4.2.1.1 Space Station Steering Committee

The Space Station Steering Committee, chaired by the NASA Associate Deputy Administrator with representatives from the major Headquarters organizations, provides a continuing formal mechanism for oversight of Space Station Program planning activities.

FIGURE 4-1
NASA HEADQUARTERS ORGANIZATION

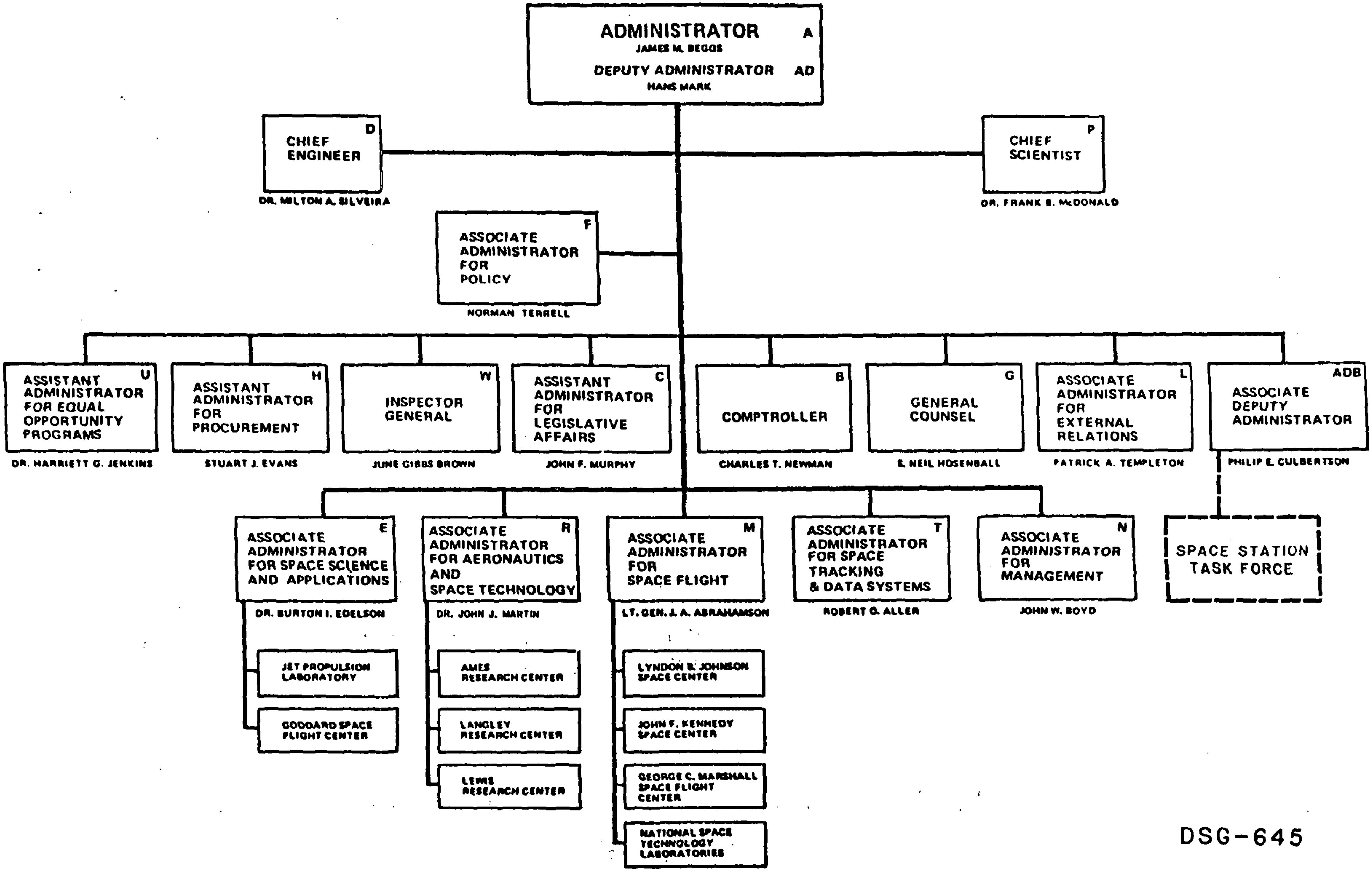
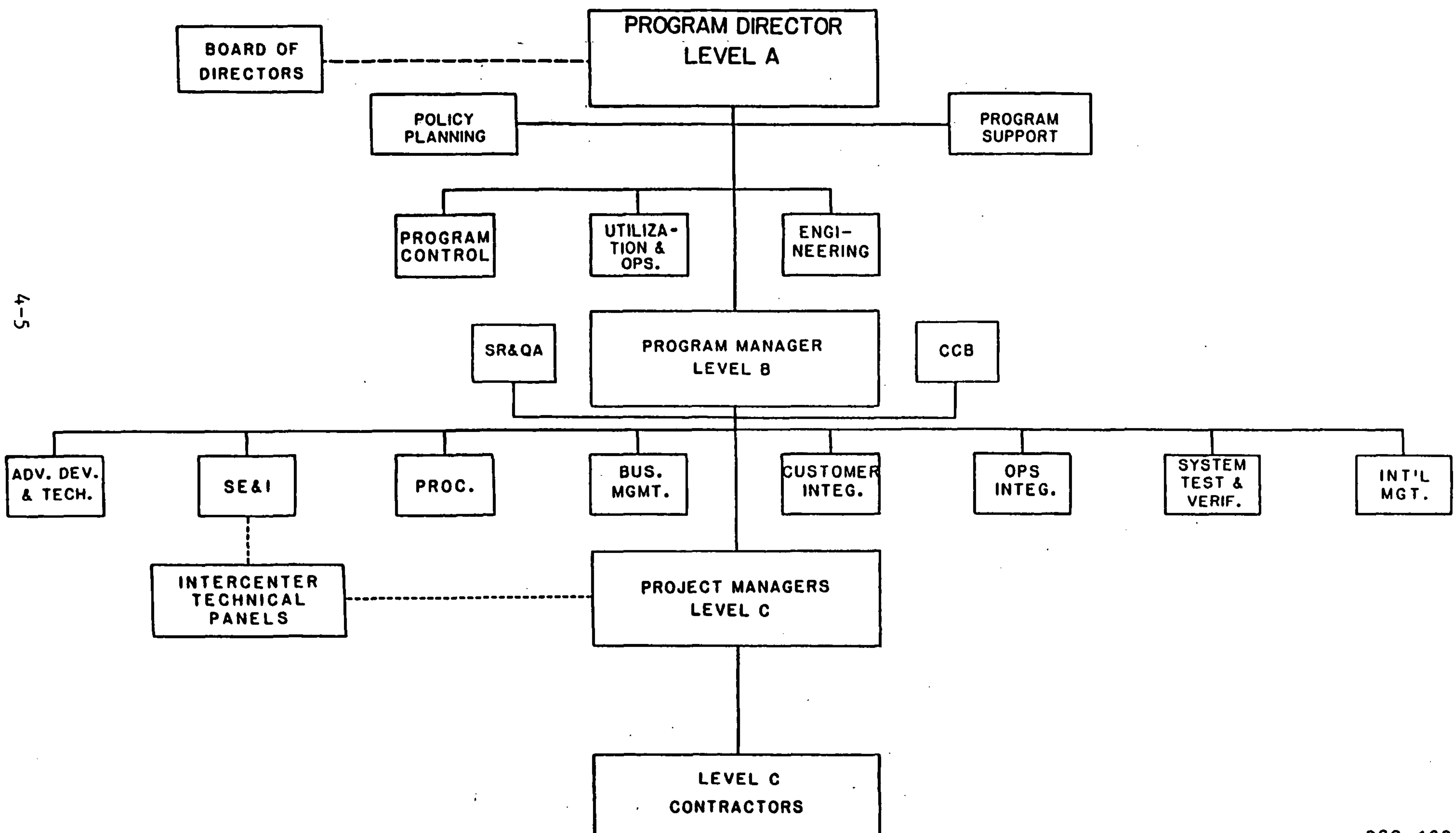


FIGURE 4-2
SPACE STATION PROGRAM/PROJECT MANAGEMENT LEVELS



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4.2.1.2 Space Station Program Office (LevelA)

The Space Station Program Office will be established at Headquarters and will be responsible for establishing Program policy, budget and schedule guidelines, and for coordinating and interfacing with all external elements including national, international, commercial, etc. This Office is also responsible for providing Program direction and management, Program requirements definition, control, utilization and operations planning and implementation, programmatic planning and control, and advanced Program planning.

4.2.1.3 Office of Space Flight

The Office of Space Flight (OSF) is responsible for the Space Shuttle, OMV and OTV, and will interface with the Space Station Program Office on all transportation requirements for the Space Station Program.

4.2.1.4 Office of Space Science and Applications

The Office of Space Science and Applications (OSSA) will be responsible for the establishment of science and applications requirements and for the definition, design, and development of science and applications payloads for the Space Station Program.

4.2.1.5 Office of Aeronautics and Space Technology

The Office of Aeronautics and Space Technology (OAST) is responsible for the management and execution of generic technology and supporting studies applicable to the Space Station Program. In agreement with a Memo of Understanding with the Space Station Program Office, OAST will manage augmentation of focused technologies applicable to the Space Station.

It is important that the focused technology augmentation tasks in OAST and the advanced development tasks in the Space Station Program be closely coordinated and integrated.

4.2.1.6 Office of Space Tracking and Data Systems

In an agreement with a Memorandum of Understanding with the Space Station Program Office, the Office of Space Tracking and Data Systems (OSTDS) will be responsible for planning, defining, and budgeting for communication tracking and data acquisition systems and networks and will interface with the Space Station Program Office in these areas.

4.2.2 Space Station Program Office

This section describes the organizational structure, responsibilities and methods of Program control which are:

4.2.2.1 Program Office Structure - TBD.

4.2.2.2 Program Direction and Review

This section describes the procedures for implementing Level A Program direction, review, reporting, and communication of Program information.

4.2.2.2.1 Program Directives System

This directive system establishes the procedures to be utilized by the Space Station Program to give direction to Level A Program participants and the Level B Program Manager. It is assumed that a similar directive system will be established by the Level B Program Manager to effect direction to Level B participants and Level C Project Managers.

The directive system defines the responsibilities and procedures necessary to submit, review, and implement Level A Program directives. The directives will give direction for the preparation of plans, documentation, procedures, and committees concerning administrative, technical, utilization, budget, schedules, and management tasks.

The Space Station Program Director or his designee shall control all Level A Program directives which will contain overall Program objectives and policies. The directives issued at Level B will guide the specific implementation of the Program.

4.2.2.2.2 Reviews and Reports

Formal periodic reviews and reports will be provided by Level A and B participants to the Program Director for control of the Program progress. The specific details for the reviews/reports will be given via the Program directive system. Essentially, these will be the monthly reports provided by the Headquarters Offices and Level B office to the Program Director. These reports will include management and technical progress as well as cost and schedule/milestone status. Major Program management reviews will be held periodically rotating from Headquarters to appropriate Field Centers.

Major requirements and technical design reviews will be conducted as a Level B function. However, because of the importance of the reviews, participation by Level A and other organizations is planned.

4.2.2.2.3 Work Breakdown Structure

The work breakdown structure for the Space Station Program is being established. In order to define Field Center responsibilities and prepare contractual documents, work packages will be defined and approved.

4.2.2.2.4 Documentation System

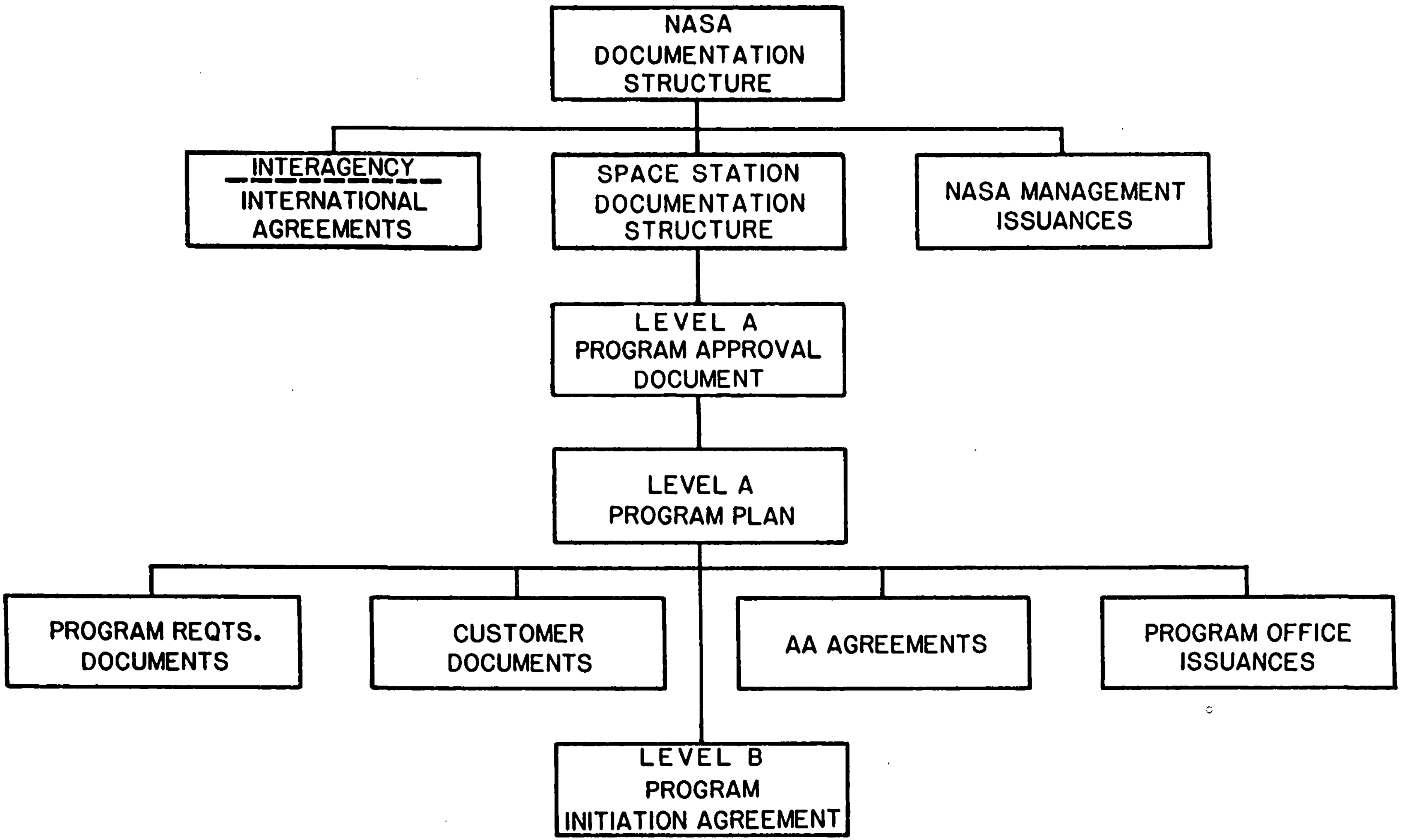
The Level A documentation system will have a structure as shown in Figure 4-3 and will give Program direction, establish policy, guidelines, and requirements, provide control of resources, budget, and schedules, and allow a free flow of Program information.

4.2.2.2.5 Information System

The purpose of the automated information system is to ensure that all information and hardware-software are compatible and consistent with current Program requirements. The system will be maintained and available to users

FIGURE 4-3

SPACE STATION DOCUMENTATION STRUCTURE



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in a timely and cost effective manner. The electronic system will be used to manage information concerning Program direction, reporting, reviews, and documentation; and will include engineering and operations data bases and networks and eventually the Space Station on-board/ground flight data systems.

4.2.3 Level B: Program Management

The Johnson Space Center has been selected as the Level B Program Management Center. Level B is responsible for management of the Space Station Program which includes:

- Systems Engineering and Integration: Establish and manage the technical content of the Space Station Program, in response to the system requirements established by Level A.
- Business Management: Manage the Program resources to the budget and schedule guidelines provided by Level A.
- Operations Integration: Assure that Space Station operations considerations are properly incorporated in the derivation of requirements and design of the system.
- Customer Integration: Manage the integration of customer requirements to assure customer needs are a pervading Program influence.
- Support of Level A: Provide overall support to Level A during budget and schedule formulation, establishment of system requirements, and other aspects of Program direction.

4.2.4 Level C: Project Management

The Level C Project Management Centers will be responsible for definition contract management, design, development and verification of all hardware, business management of the projects, and management of all element design and development contractors.

4.2.4.1 Advanced Development

NASA has established seven inter-center teams to conduct advanced development activities for high potential technologies to be used in Space Station design and development. The assignments are intended to identify emerging technologies for advanced development for Space Station design and to establish test beds into which prototype technology hardware could be integrated, tested, demonstrated, and evaluated.

The Advanced Development Program will be formally initiated by Level A through the issuance of a Program Directive to the Level B Program Manager requesting integrated advanced development plans. These plans will identify activities to be pursued for both the initial and evolutionary Space Station, funding requirements, schedules, and major decision points. Level B will negotiate these plans with the lead Centers. Approval of these plans by Level B will constitute project agreements. Although the plans will be multi-year in nature, the proposed operating year activities will be reviewed and approved annually.

Inasmuch as focused technology builds upon the generic research & technology base, the Center(s) performing the generic activities will be responsible for conducting the focused activities. Agreements will be negotiated between Level A and the appropriate Headquarters offices for the conduct of this work through established mechanisms (i.e., RTOP's and POP's). Funding for the remaining Program elements will be based on the plans agreed upon by Level B and the lead Centers.

The advanced development Center assignments are:

- Attitude Control and Stabilization System: MSFC is lead Center of a team which includes JPL and JSC, with LaRC, participating in a supporting role.
- Data Management System: JSC is lead Center in a team which consists of GSFC and KSC. Support will be provided by ARC, NSTL, JPL, and LaRC.
- Auxiliary Propulsion System: MSFC is lead Center in a team which includes LeRC, JPL, and JSC.
- Environmental Control and Life Support System: JSC is lead Center in a team which includes ARC.
- Space Operations Mechanisms: MSFC is lead Center in a team which includes JPL, JSC, and LeRC, with LaRC in a supporting role.

- Thermal Management System: JSC is lead Center in a team which includes GSFC, LeRC, and MSFC.

- Electric Power System: The inter-center team is JSC, LeRC, and MSFC, with JPL in a supporting role as appropriate. The lead Center will be designated later.

4.2.4.2 Work Packages

For the purpose of managing and defining the Space Station Program, the Space Station Program elements for both the initial and growth operational capabilities will be categorized into work packages. Each work package will consist of a collection of functions which in any design/development activity will evolve into hardware, software, and interfaces. The work packages will be defined in detail prior to RFP release.

5.0 TECHNICAL APPROACH

This section describes the overall technical approach and activities for conducting NASA Headquarters (Level A) tasks. The activities include the top level approach for design, development, and integration of the Space Station, and its elements. Activities include defining, assessing, and integrating utilization and operations plans and requirements into the Program, defining and developing advanced development and technology activities, establishing safety, reliability, quality assurance and maintainability criteria, and assessing the overall environmental effects of the system on the near Earth environment.

5.1 UTILIZATION

Utilization is the term applied to the overall process of identifying Space Station customers, defining and refining their requirements and needs, and integrating both requirements and customers into the Space Station Program design, development, and operations.

5.1.1 Rationale

The Space Station will function as a national resource that is available to a wide variety of customers including NASA and other domestic agencies, international, science and technology agencies, domestic and international commercial enterprises, and the Department of Defense. A prime measure of success of the Program will be the degree to which this resource is utilized by its customers. In order to accomplish the goal of high utilization, the Space Station must be "customer friendly" in terms of cost and useability. Dealing with customers, potential and committed, and ensuring that they are a major force within the Program is the primary responsibility of the utilization organization in the Space Station Program.

5.1.2 Objective

The objectives of the utilization function are:

- Develop, enlighten, and maintain the Space Station Program customer communities/constituencies which include government, industry, international, academic (science & technology), and national security communities.
- Provide the management mechanisms for representation of customer (internal and external NASA) interests and requirements through all phases of the Space Station evolution including design, development, and operations.
- Develop, control, and maintain Program, mission, and operations requirements, as well as the Space Station Program performance envelope, and ensure new requirements are reflected in advanced Space Station definition design concepts.
- Ensure all customers are accommodated on the Space Station according to their needs.
- Develop and implement policies (pricing, commercialization, services, etc.) that enhance user access and use of the Space Station.
- Evaluate effectiveness of customer interface with and use of the Space Station.
- Improve the access to and ease of using space.

5.2 OPERATIONS PLAN

Emphasis is placed on new operational factors that arise in association with a permanently manned orbital facility, means to operate the system in the most cost-effective manner, and a customer-oriented operational approach to achieve maximum benefits from the system.

Management of the Space Station will divide operations between flight and ground systems in such a way that the capabilities of each are most effectively utilized. System autonomy will minimize ground control of the Station and on-board machine autonomy will minimize crew involvement in system monitoring allowing the crew to maximize high return activities in support of customer missions. The Space Station will provide non-mission-unique services such as data processing and communications.

5.2.1 Flight/Ground Operations

The various configurations that the Space Station will go through during its ground and space buildup will require different levels of launch site and ground control/support. Launch site support will be provided to test systems and interfaces for STS launches. Real-time ground support will be provided for the Space Station in the form of flight and system monitoring and assistance during on orbit assembly, activation, checkout, and verification. Ground support will continue until confidence is achieved in the system's element operation to permit autonomous operation by the Space Station. Subsequent ground monitoring will be limited to periodic review of data.

5.2.2 Logistics

An integrated logistics system will be developed and implemented to provide cost-effective life of the Program support to the Space Station. To meet this objective, logistics will be addressed throughout all Program phases (concept development, preliminary design, final design, production and operations) in an iterative fashion. This iteration will provide a forum for continuous dialogue between customers, designers, engineers, operators, and maintainers, as well as other support elements, to assure the identification, consideration, and integration of support requirements across all Space Station Program activities.

Space Station logistics will be viewed from a total system perspective to derive Program cost benefits. Functional elements of logistics that will be addressed continuously and integrated over the Program life in conjunction with hardware design include the following:

- Maintenance and repair;
- Supplies and materials including spares and repair parts;
- Support equipment including tools and shop aids;
- Training;
- Packaging/handling and transportation;

- Facilities; and
- Data management.

5.3 ENGINEERING ACTIVITIES

5.3.1 Unique Considerations

The Space Station, unlike typical spacecraft systems, will be designed to be a long-lived asset in space. This capability will exist because the Space Station will be designed to be improved and modified by increments so that its capability will be enhanced in an evolutionary manner. Another benefit of the design concept involving modifications by increments is that the long lived aspect of the system need not require the ultimate in "traditional" reliability enhancements with the attendant cost consequences.

5.3.2 Systems Engineering and Integration (SE&I)

The systems engineering and integration (SE&I) efforts consist of tasks required to define and analyze elements, systems, and subsystems of the Space Station Program. The Level B Program Office at Johnson Space Center will be responsible for establishing and implementing an in-house SE&I capability maximizing the use of the expertise Agency-wide.

The SE&I function shall provide systems engineering and systems integration, programmatic activities, and products. The systems engineering function shall provide systems analysis, systems trades, definition synthesis, configuration analysis, systems requirements, maintainability, technical managers, and logistics. Systems integration shall provide requirements integration, Interface Control Documents (ICDs), configuration management, specifications, and commonality.

5.3.3 Hardware Commonality

The Space Station shall incorporate hardware commonality to the maximum possible extent to minimize cost through significant cost avoidance, to simplify integration, maintenance, and spare requirements, to provide compatibility among all elements, to assure continued supply throughout the Space Station life, and to enhance system evolution.

Examples of trade issues requiring resolution during the Space Station definition phase include:

- Level of design commonality among Space Station elements and within systems;
- Level of modularity;
- Development of cost-effective management and technical strategies to control common systems; and
- Effect of commonality on user friendliness.

5.3.4 STS Interface

Planning activities will be initiated during the definition phase to define and establish Space Station interfaces with the STS including logistics planning, technical interface, safety requirement, and defining unique accommodations.

5.3.5 Tracking and Data Relay Satellite (TDRS) Interface

Planning activities will also be initiated during the definition phase to define and establish interfaces with the TDRS for communications accommodations.

5.4 ADVANCED DEVELOPMENT AND TECHNOLOGY

The planned Space Station capabilities pose challenges never before encountered in space. These challenges include an indefinite on-orbit presence, routine accessibility via the Shuttle, permanently manned occupancy, provisions for maintenance and repair in space, built-in growth potential, and user accommodations. Interpretation of these unique requirements has led both NASA and industry to conclude that the current state of technology in selected disciplines is inadequate to permit building the desired Space Station without compromising capability and/or recurring cost.

Therefore, a major endeavor for the Space Station Program is to initiate technology development activities that will enable and support the desired system.

5.4.1 Objectives

The objectives of the Advanced Development Program are consistent with and support Agency goals for planning, implementing, and operating a Space Station system. The Program serves as the umbrella for all technology development activities starting with the focusing of generic technologies to the Space Station application, development of prototype technology components/subsystems, their integration and testing in discipline test beds, and flight experiments and demonstrations as required. The specific Program objectives are:

- To provide advanced technology alternatives for the initial and evolutionary Space Station which optimize the system's functional characteristics in terms of performance, cost, and utilization.
- To develop methodologies for enhancing and facilitating the transfer of new and advanced technologies from technologists to system planners/developers.
- To interface with industry to establish "informed" contractor teams to support the development and operational phases of the Space Station Program.

5.4.2 Approach

The Advanced Development Program is intended to support the Space Station, in its initial and evolutionary configurations, by providing advanced technology options that have the potential for enhancing the systems performance and reducing life-cycle costs. The Advanced Development Program has four key activity elements: (1) Focused technology; (2) prototype technology; (3) test beds; and (4) flight experiments. The focused technology activity is targeted at ensuring that a clear and proper application focus is provided to the generic Research and Technology base Program. It is also necessary that advocacy and funding is made available to continue technology development through demonstration at the laboratory breadboard level. The prototype technology activity continues the development process into prototype components. Once developed, the prototye hardware will be integrated into appropriate subsystems and cycled into test beds for test and evaluation. Although the test bed approach will be primarily manifested in ground-based facilities, the Shuttle capability will be exploited for flight experiments. This will enable NASA to validate the performance of critical subsystems in the space environment which cannot otherwise be validated in ground tests (i.e., to verify and quantify calculated performance, to identify unforeseen anomolies, and to update engineering design criteria).

The technology expertise of both NASA and industry will be incorporated. Industry involvement will occur in a dual manner: (1) As contractors supporting NASA's focused and prototype technology activities; and (2) as contractors performing portions of the Phase B system definition procurements. NASA Centers will implement and operate test beds and will assure their availability and use in testing and evaluation of advanced technologies and new techniques as described in Section 4.2.5 of this document and in Book 4, Space Station Advanced Development Program.

5.5 SAFETY, RELIABILITY, MAINTAINABILITY, AND QUALITY ASSURANCE (SRM&QA)

5.5.1 SRM&QA Objectives

The Space Station shall be designed to be safe, highly reliable, maintainable, and have an indefinite useful life. The SRM&QA objectives for Space Station are to assure that these Program design requirements are met.

5.5.2 SRM&QA Approach

The Space Station SRM&QA approach will be in conformance with NASA Management Instructions and Space Station Program requirements, and implemented by appropriate SRM&QA programmatic requirements documentation. A NASA SRM&QA organization will be responsible for ensuring that SRM&QA is a part of the design and operation of the Space Station.

The Space Station Program offers an opportunity to reduce "the cost of doing business in space" without compromising safety or reliability. Trade studies will be conducted to identify and assess the areas of potential cost reduction.

The SRM&QA Program for the Space Station will include:

- A Safety Program implemented to assure that hazards inherent in Space Station flight and ground systems are identified and controls are established to eliminate the hazards or minimize them by incorporating safety factors, safety devices, caution and warning devices, redundancy, backup systems, and/or procedures;

- A Reliability Program implemented to assure through various management, engineering, and test activities that Space Station hardware design meets Program objectives and performance requirements;

- A Maintainability Program implemented to assure that all Space Station hardware is designed to be maintainable by servicing, replacement, or repair on-orbit, and which is closely integrated with other functions such as safety, reliability, quality assurance, logistics, and verification;

- A Quality Assurance Program implemented to validate the acceptability and performance characteristics of conforming articles and materials to assure the detection and correction of all departures from the design and performance specification during the design, development, production, and on-orbit phases of the Program;

- Test Program: Prior flight and/or ground test will have demonstrated the system elements are capable of meeting mission requirements for all mission phases; for these system elements which will not have been verified by flight and/or ground test, engineering analyses and/or simulations will substantiate their capability of meeting mission requirements. Significant failures experienced during test programs on Space Station hardware shall be analyzed and corrected action as appropriate shall be accomplished; and

- Space Station flight systems, ground support equipment (GSE) and facilities shall be designed with appropriate safety factors and proven qualified components. Hazards that cannot be eliminated will be minimized by incorporating safety devices, warning devices or signals, redundancy and fail-safe features. Hazards inherent in the design, test, and operations shall be identified and control measures established to preclude personnel injury or hardware loss.

5.6 HUMAN PRODUCTIVITY

The goal of human productivity is to maximize the productivity of the Space Station crew within the available resources and existing operational constraints. Since there are many factors that contribute to productivity, there will never be sufficient resources to pursue elegant implementations to all of these factors. Thus, the central issue in the program is to determine the distribution of resources that will ultimately lead to the greatest productivity of the crew. The essential strategy of this effort is to gather all of the crew-related facilities and activities within a single focus for the purpose of conducting engineering trade studies to identify the optimal combination of the most cost-effective factors contributing to productivity. Once identified, these factors are integrated into a coordinated approach to productivity and then employed as guidelines in the development of hardware and crew procedures.

5.7 ENVIRONMENTAL IMPACT ASSESSMENT

In order to comply with all Federal regulations, NASA will assess the potential impact to the environment which may result from the implementation of this Program.

6.0 PROCUREMENT APPROACH

NASA will procure Space Station hardware in a manner designed to accomplish the Agency goals. The acquisition strategy is keyed to the policy of NASA performing the SE&I in-house. Recognizing that the Space Station will be developed incrementally and constrained by the availability of budget authority, the Program will be based on design to cost.

The initial procurement is for the conceptual definition of the total capability and the detailed definition and preliminary design of the initial operational capability of the Space Station. A single Request for Proposal (RFP) will be released from which selections will be made for all work package contracts. Two or more fixed-price definition contracts will be awarded for each work package. Work package contractors shall perform analyses and trades in support of the Level B SE&I as appropriate through completion of the Interface Requirements Review (IRR). Contractors may propose on one or more of the work packages. Proposals will be evaluated by a Source Evaluation Board (SEB) in accordance with applicable regulations. The Administrator will be the Source Selection Official. After source selection, the negotiation, contract award, and management will be the responsibility of the Center holding the respective work package assignment.

The definition contracts, lasting 18 to 24 months, will define system requirements, develop supporting technologies and technology-development plans through ground, test bed, and flight experiments, perform supporting systems and trade studies, develop a preliminary design, define system interfaces, and develop plans, cost estimates, and schedules for the succeeding design and development phase. By penetrating the design to the element level and demonstrating subsystem technology, NASA will be able to base Program development decisions and development contractor selection on a greater understanding of Program and technical risks.

Competition for the next phase (i.e., design, development, test of flight systems) will be limited to the definition phase contractors unless it is in the best interest of the Government to alter this approach. New procurement documentation and new SEBs will be established for the next phase. While evaluation criteria will be developed by these new SEBs, it is anticipated that contractor products and performance during definition will be considered in the evaluation process. The design and development contractor selections will be made by the Administrator.

7.0 RESOURCES APPROACH

This section describes the resources management approach consisting of the budget process, the budget, manpower, and facilities.

7.1 RESOURCES MANAGEMENT

An approach is being developed for the Space Station that provides for an evolutionary, methodical definition of Program costs. Comprehensive analysis will be performed to ensure that Program implementation is consistent with established cost restraints. Lessons learned from other programs have been reviewed to ensure that maximum benefit is gained from NASA's past experience.

Program definition reviews are being and will continue to be held prior to inclusion of the Space Station implementation requirements in the NASA budget request to ensure that all elements of the Space Station are well defined and understood. This approach allows knowledgeable individuals with no vested interest in the Space Station Program to critically review and evaluate the proposed Program and plans and recommend appropriate changes before major Agency commitments.

7.2 BUDGET PROCESS

The budget process is being developed for the Space Station Program that utilizes proven as well as new and innovative cost management techniques to achieve the best Program within available cost constraints. Reporting, management control and visibility, and cost assessments are being incorporated into a comprehensive information system.

7.2.1 Budget Formulation

The Program Director will establish budget guidelines including reserves for Program cost growth and changes. Program budgets will be developed by the Level B Program Office for submittal to the Level A Director for each annual NASA budget submission. Because of the two-year lead time in the budget process, it is important that all parties to the budgeting process provide appropriate reserves for contingencies.

The budget will be evolutionary in its formulation. Initially, Level A shall require that Level B define the budget at a detailed task level for the definition phase. Parametric estimates will initially be employed for the development phase. As the Program matures and development contracts are established, the budget will be formulated on detailed engineering build-up estimates and modified where required by results or Program independent assessments performed by Level B for Level A.

7.2.2 Budget Allocation

Upon Program Director approval of the operating plan, the Level B Program Manager will implement the budget allocation.

7.2.3 Budget Statusing

A state-of-the-art resources information system shall be developed by Level B to provide current status of Program costs to managers at all Program levels. The system will emphasize timeliness, completeness, and accuracy, and will be structured to emphasize anomalies that require management attention. Periodic Program review meetings, internal to NASA, will be held, at which cost variances and total projected costs will be reported by the Program Manager to the Program Director.

7.3 BUDGET

7.3.1 Development Phase Budget Plan

The initial Space Station capability development phase will utilize $8 billion (constant 1984 dollars) and covers the period FY 1985 through IOC. It will include design, development, test, launch, and on-orbit checkout of the initial Space Station elements.

7.3.2 Operational Phase Budget Plan

Operational phase budgets will be submitted by Level B to Level A for subsequent updates of this plan.

7.4 FACILITIES

The Space Station Program may require funding for construction for new facilities. Maximum use will be made of existing and/or modification of existing facilities. Facilities will be required for the following types of functions: Technology development, subsystem development, manufacturing, test, design verification, training, checkout, servicing, integration, and launch, and mission support.

A long-range facility plan will be developed in FY 1984 by Level B for Program Director's review and will be reviewed and, if necessary, modified annually.

7.5 MANPOWER PLAN

Manpower planning will be an integral part of the budget process for both civil service and contractor manpower. Program manpower will be reviewed monthly.

8.0 SCHEDULES

8.1 SCHEDULE MILESTONES

The Program Director will establish and maintain the Level A Program milestones as shown in Figure 8-1 and as described in Table 8-1. This overall schedule will be supported by logic networks and schedules prepared by both Headquarters and Level B program participants to provide the basis for top level planning and performance measurement. Selected milestones having program- wide implications or reflecting major commitments and agreements will be designated as Level A controlled milestones. Once selected, the Level A controlled milestones will be changed only with the approval of the Program Director.

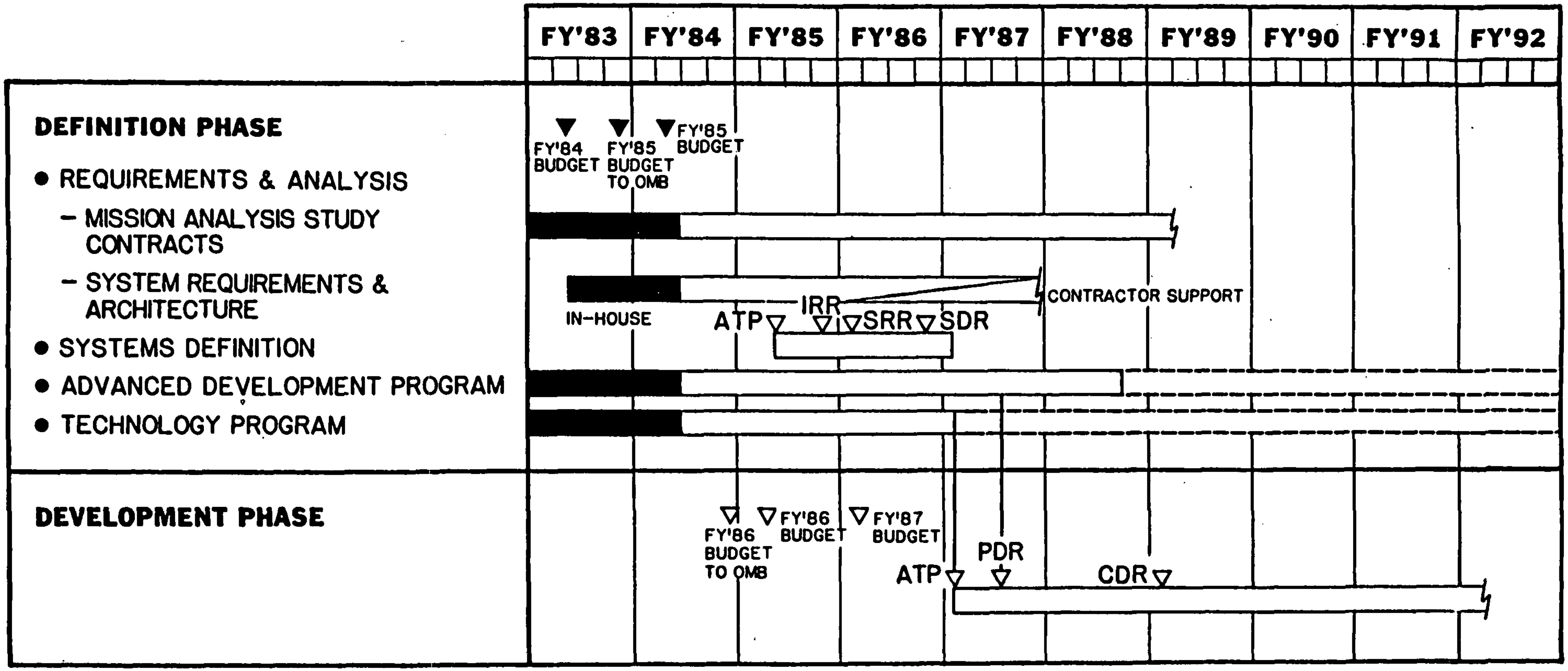
Similarly, the Level B Program Manager and Level C Project Managers will identify key milestones to provide the basis for performance measurement of each program element (projects, technology development activities, supporting research, etc.).

Revisions to the schedules will be controlled by the Level A Program Director for Level A milestones, Level B Program Manager for Level B milestones, and Level C Project Managers for Level C Project schedules.

This Program Schedule System will be integrated into and be a major part of the Management Information System established by the Space Station Level B Program Office.

FIGURE 8-1

SPACE STATION PLANNING SCHEDULE



ATP – AUTHORITY TO PROCEED
CDR – CRITICAL DESIGN REVIEW
IRR – INTERFACE REQUIREMENTS REVIEW
PDR – PRELIMINARY DESIGN REVIEW
SDR – SYSTEM DESIGN REVIEW
SRR – SYSTEM REQUIREMENTS REVIEW

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MILESTONE DESCRIPTIONS

TABLE 8-1

IRR - Interface Requirements Review

An in-depth review of Space Station configurations and establishes the Space Station configuration and system interfaces, as described in the Configuration Description and Interface Control Documents.

SRR - System Requirements Review

A review of the Program systems requirements resulting from element design studies as contained in System and Subsystem Requirement Documents. These documents will constitute the Level B Baseline and will be under configuration control.)

SDR - System Design Review

A review of proposed system and subsystem element designs, technology, preliminary ICDs, specifications, and final system design reports.

PDR - Preliminary Design Review

A review of preliminary designs to satisfy Space Station requirements, specifications, ICDs, and verification needs. These design documents will be established as Level C Baseline and will be placed under configuration control.

CDR - Critical Design Review

An in-depth review of final design prior to commitment to manufacture.